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Biology and Distribution of Humpback Shrimp (*Pandalus hypsinotus*) in the Tatar Strait (the Sea of Japan)

by

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Abstract

Seasonal observations on *Pandalus hypsinotus* population in the Tatar Strait (the northern part of the Sea of Japan) were made in 1996-1998. Females released larvae in June. Oocytes developed from August to December. Fertilisation and spawning occurred in winter and females therefore bore the eggs on pleopods for six months. However some females with outer eggs were found in samples through the whole year. With the help of normal probability plot five age groups were distinguished. Carapace lengths in the first group varied from 16 to 27 mm, second - 22-34 mm, third - 30-43 mm, fourth - 37-48 mm, fifth - 44-52 mm. Two first groups included 97% of all males, the third group - 100% of all intersexes, the fourth and fifth groups - 85% of all females with inner roe. The probable age of the first group is 1+ and males therefore change their sex at the fourth year. Migrations to the shore were found in December. Four isolated patches were distinguished in spatial distribution of population in 1998. Dynamics of size structures indicate that southern patches may develop independently while the northern one may be recruited by immigrations of mature shrimps. Problems of fishery recommendations in connection with existence of large-scale migrations across the patches are discussed.

Introduction

The humpback shrimp *Pandalus hypsinotus* Brandt, 1851 is widely distributed Pacific species which occurs from the Bering Sea to the south up to the Strait Juan de Fuca along American coast and up to Honshu along the Asian coast (Butler, 1964; Kurata, 1981). In Russian waters the largest commercial population occurs in the Tatar Strait from 46°00' N to 50°30' N along both continental (west) and Sakhalinian (east) shores. The mature part of population occupies depths within 80-400 m (Tabunkov, 1982; Galymzyanov, 1994) while juveniles may be found almost in the intertidal (Sokolov, in press). The depths in central and southern parts of the Strait exceed 500 m (Fig.1) and therefore both western and eastern parts of populations are separated, while in the northern part they are united in common patch. The main biological patterns of American and Japanese populations are studied rather completely (see: Butler, 1964, Kurata, 1981). However data on biology of the Tatar Strait population based on short-term observations in different years are limited by information on spatial distribution and fisheries dynamics (Tabunkov, 1982; Galymzyanov, 1994). Conclusions on reproduction and growth (Tabunkov, 1982) need revision. The goal of this investigation therefore was to study reproductive cycle, age structure and patterns of spatial and temporal distribution of this species in the Tatar Strait particularly in its eastern part.

Material and Methods

The samples were collected in 1996-1998 (Fig.1) by pyramidal shrimp traps with two lateral entrances (Kurata, 1981: fig. 10). The size of net, measured as distance between neighbour knots, was 16 mm. Baited with frozen pollock the traps were consequently attached to common rope and thus formed the order. The distance between traps in the order varied from 7 to 10 m, and their number per order varied from 500 to 700. The orders were normally left in the water for 2 days. Co-ordinates of both ends of the order were registered by satellite system of communication (GPS) and depths were measured by echo sounder "FURUNO".

Each sample included all animals that had been collected from 10-50 traps in common basin. The humpback shrimps were separated from other animals and then they were counted, weighted and measured for carapace length. For sex determination endopodites of the first pleopods were examined. Either presence or absence of the sternal spines (McCrary, 1971) were also mentioned. Both females with outer eggs and with developing ovaries ("inner roe") were distinguished. Measurements were recorded to the nearest 0.1 mm. Condition of carapace was evaluated according to 3-point scale (Ivanov, Stolyarenko, 1990): 1 - carapace firm, 2 - carapace is "firming", 3 - carapace is soft. Thus approximately 43 000 individuals from 630 samples (Fig.1) were examined in 1996-1998.

For reproductive cycle research data from all samples were used. Data for age structure and temporal changes were obtained from control polygons which were bordered by latitudes, longitudes and depths (see Fig. 3-5, 7).

Number of age groups, their size-borders and mean sizes were calculated by the use of normal probability plot (PC program "STATISTICA ® for Windows ® v.5, 0"). This method is almost the same as that of probability paper (Harding, 1949; Cassie, 1954) and differs only by axis indexes. In our method the size is given on abscise axis and expected normal value (updated normal probability) is given on ordinate axis, while on probability paper the normal probability is given on abscise axis and the size is given on ordinate axis.

Maps of catch distribution were extrapolated by the method of spline-approximation (Stolyarenko and Ivanov, 1988) with the help of PC program "Map Designer ® v.2.1".

Results and Discussion

Reproductive cycle and sex change

Data from spring samples showed that the absolute majority (99%) of females had outer eggs ("outer roe": Fig. 2); intersexes at that period were not registered. Females, which had been released larvae, appeared in June. Both females and intersexes with developing ovaries ("inner roe") occurred in catches from July to December. The average volume of ovaries under carapace had been increasing from summer to winter (Buyanovsky, in press). Intersexes also occurred in samples up to December. In summer and fall primiparous females (with sternal spines) were rarely registered, in December (1998) the ratio between them and intersexes was 12:368. It seems therefore that majority of intersexes turn into females in winter before copulation.

It should be mentioned that some females with outer eggs were registered in catches at different seasons; in fall and winter they varied from 10 to 30 percent (Fig. 2).

Absolute majority (95-99 percent) of shrimps had firm (stage 1) carapaces throughout the year. Probably it is caused by decrease of moulting shrimps activity and they were not therefore attracted by lure in traps. Registration of both intersexes and females with inner roe in summer however indicate that moult occurs at that period, probably after hatching. According to previous investigations based on trawl samples moult also occurred in summer (Tabunkov, 1982). The periods of suggested moult coincided with the season of minimal catches (see below).

Thus the following schedule of the reproductive cycle of *P. hypsinotus* population in the Tatar Strait may be suggested. Gametogenesis activates at the middle of summer after hatching and moult. In winter it is followed

by spawning and eggs laying. Hatching occurs at the beginning of summer and ovigerous period therefore lasts about six months. Thus time of spawning in the Tatar Strait differs clearly from that in other regions where it occurs from May to September (Igarashi, 1951; Butler, 1964; Kurata, 1981; Bukin and Zgurovsky, 1988). The longevity of ovigerous period however is close to data obtained both for Funka Bay, southern Hokkaido (Igarashi, 1951) and British Columbia (Butler, 1964). Sex change in the Tatar Strait begins mid-summer and is over by spring of the next year.

The phenomenon of annual presence of egg-bearing females was mentioned earlier both for this region (Tabunkov, 1982) and for the Great Peter Gulf of the Japan Sea (Bukin and Zgurovsky, 1988). It is caused by variations in periods of egg carriage among individual shrimps and possibility of juveniles production at different seasons may increase resistance of the population in general. However the baseline causes of such variations are still unknown.

Age groups

Application of probability paper for analysis of length frequency distributions with further separation of age groups is permitted only if annual generations are produced once a year and if they appear through a short period. The period of eggs release in the studied population seems to be rather short and spawning occurs once a year (Fig.2; the effect of unreleased females on age-structure will be discussed separately). Therefore this method may be applied for further analysis.

Before age-group separation data on measurements made in 1998 were divided into three bands which corresponded to three isolated patches and differed temporally (Fig. 1D, 3). The use of normal probability plot (Fig. 3D) allowed to distinguish 4 monomodal size-groups in patches A and C (Fig. 3 A, C) and 5 groups in patch B (Fig.3 B). Size-borders for three first groups ranged between 16-27, 22-34 and 30- 43 mm respectively. The fourth group was clearly observed only in patches A and B and its borders varied in ranges 37-48 mm while in patch C its borders were rather vague. The traces of the fifth groups were found only in patch B, and this group might be indicated only by presence of slope on probability plot (Fig. 3D) while scarce data on shrimps over 45 mm (Table 1) did not allow to define its upper border.

The average sizes in respective groups were rather close (Table 1) and distinctions between patches did not exceed 3 mm.

Thus similarity of both size-borders and average sizes for shrimps which were collected both in different regions and at different seasons indicate that defined groups are not occasional but exist owing to age differences, and they therefore may be regarded as age groups. However additional criteria are needed to check obtained data. Due to the fact that pandalid shrimps development is accompanied with sex-reversal, their sexes may be applied as such criteria for age determination.

Size-structure of sexual groups

Frequency distributions of males sizes in all patches were clearly bimodal and absolute majority (from 96 to 99 percent) of males occurred in ranges of the two first age-groups, i.e. they were less than 35 mm (Fig.3 A-C). Intersexes were numerous only in patch C (Fig.3 C) and almost 100 percent of them occurred in the ranges of the third age group (30-43 mm). In patches A and B they were not numerous (Fig. 3 A-B) and that group therefore was not observed there as clearly as in patch C. Sizes of multiparous females (with inner roe and without sternal spines) varied from 30 to 50 mm and the part of shrimps that occurred in the fourth age group (37- 48 mm), varied between the patches from 77 to 96 percent. Sizes of egg-bearing females ("outer roe": Fig. 3) varied in the same ranges and the part of shrimps which occurred in the fourth group varied between the patches from 56 to 75 percent, while the rest specimens of this category occurred in the previous, third, age group. Data on other categories (primiparous females, females that had been released larvae, etc.) were too scarce for representative estimations.

These data confirm the assumption that size-groups distinguished on normal probability plot are not occasional but caused by age differences. The most noticeable deviations were mentioned only for egg-bearing

females. Due to delay of both hatching and following moult these shrimps do not grow and their sizes in summer and fall (Fig.3) therefore correspond to previous age group and overlap with those of intersexes. Thus, when it is necessary to establish population age structure at the second half of the year, the egg-bearing females which sizes correspond to the third group should be removed from this group and be added to the fourth group. Due to its scarcity the fifth group for fishery investigations in this region may be ignored.

Due to the fact that trap catches selectively, size-structure of shrimps below 17 mm cannot be established and their real age cannot therefore be estimated directly from histograms. The juveniles (age 0+) were however found near the shore (depth 0-0.5 m) in October 1998 (Sokolov, in press). Their modal sizes were about 10 mm. The growth throughout the first year is rather fast and the mean length for this period may increase up to 25 mm (Butler, 1964; Kurata, 1981). Therefore the age of the first group (16-27 mm) may correspond to 1+, and the numbers of other groups (Table 1) correspond to their ages in full years (II - 2+, III - 3+ - etc.).

Thus majority of humpback shrimps from the Tatar Strait live about five years, while in other regions they live from 3 (Butler, 1964) to 4 (Kurata, 1981) years. The “additional” years are caused by sex change in fall at the fourth year, while in mentioned regions sex change occurs during the second or third year. The shrimps of the western part of the Japan Sea (the Great Peter Gulf) probably live over 5 years (Bukin, Zgurovsky, 1988) and the fifth age group (Fig. 3B,D) therefore may really exist. The mean sizes of intersexes in the Tatar Strait were less by comparison with those from the West Hokkaido (approximately 40 mm; Kurata, 1981) and they were almost the same as in May-June in the in Great Peter Gulf (36 mm; Bukin and Zgurovsky, 1988).

Annual dynamics

Annual changes in catch values showed decrease from April to July with further increase in August (Fig.4A). During the fall the catches remained at the same level. Decrease observed in December 1997 was not found in 1996 and 1998.

Reduction of catches in May-June was caused by decrease of male catches while those of females decreased only in the second half of summer (Fig.4B). Time of male catches reduction coincided with time of moult, which occurred in the Strait in the first half of summer (see above). Obtained data indicate that females pass moult later than males. Intersexes, however, appeared simultaneously with “inner roe” females (Fig.4B).

Seasonal migrations

For the period from April to November the area of maximal catches was located deeper than 220 m, while in December it shifted to 190-200 m (Fig.5). The same trends were observed in both 1996 and 1998 but due to a smaller range of observed depths they were not expressed so clearly. Additional investigations need both to confirm existence of such migrations and to establish their causes, but it is evident that they coincide with spawning, which occurs in winter. Decrease of catches in December 1997 (Fig. 4A) also might be caused by bathymetric migrations.

Spatial structure of population

During observations in the same periods of 1996-1998 spatial distribution of shrimps was patchy (Fig.6). In 1996 extensive patch was located in the north-eastern part of the Strait to the north of 49°N (Fig.6A). In following years its area decreased and the catches remained almost the same only in the central part (Fig.6 B-C; Table 2) while they significantly reduced both in northern and southern (48°30'-49°00' N) regions.

Shrimps of carapace length 29-30 mm were the most numerous in this patch in 1996 (Fig.7A). This length corresponds to age 2+ (Fig.2, Table 1) and such shrimps therefore represented generation which had been produced in the summer of 1994. Shrimps of elder generations (both of 1992 and 1993) were also numerous while the first age group corresponding to generation of 1995 (sizes below 27 mm) was scarce. In 1997 (Fig.7B) shrimps of generations which had been produced both in 1994 and 1995 (modal sizes 31 and 37 mm respectively) were the most numerous, while generation of 1993 (with expected modal sizes of 40-42 mm) significantly reduced in

number. The same size structure was observed in 1998 (Fig.7C) but the first age group (generation which appeared in 1997) that year was more numerous than in previous years.

Extension of research area in 1997 allowed to find the second patch which was located in the eastern part of the Strait between 47°50' N and 48°45' N (Fig. 6 B). Next year its borders extended to the south whilst the catches in the northern part significantly reduced (Fig.6C, Table 2). The range of depths occupied by the patch also extended (Table 2). The patch therefore “shifted” to the south and its square increased.

In 1997 the shrimps with modal size 24 mm were the most numerous in this patch (Fig.7D). These specimens may represent generation, which appeared in 1996. This generation remained the most numerous also in 1998 when it transformed to the second (Fig.2, Table 2) age group with modal size 29 mm (Fig.7E). Previous generations (appeared in 1995 and 1994) also remained and the number of large shrimps (longer than 40 mm) therefore increased. Catches of shrimps belonged to the first age group (carapace length is less than 27 mm) were less than in previous year but as in 1997 they were the highest within observed region.

The third patch was found in 1998 in the south-eastern part of the Strait within 46°35'N and 47°15'N. Both model data (Fig.6B) and lack of fisheries in that region before (personal information of captains) point out that the patch appeared only that year. Shrimps of generation which had been produced in 1996 (modal sizes 29-30 mm; Fig. 3A) were the most numerous.

The western part of the Strait was observed in less degree (Fig.1). The distribution models however indicate that in 1997-1998 the western patch also shifted to south. Data on size-structure show that both years the generation of 1996 was the most numerous. (Fig. 8 F-G). Density of the first age group (below 25 mm) in 1998 was less than in 1997.

Thus both lessening of the northern patch and extension of the southern patches were the main trends of spatial dynamics of *P.hypsinotus* population in 1996-98.

Dynamics of size-structure in the central (47°30' - 48°30' N) patches of both eastern and western parts of the Strait (Fig.8 D-E) indicate that densities of separate generations may be predicted from respective data in previous years. Those patches therefore may be recruited without immigration of mature shrimps. The juveniles settling in the coastal area (Sokolov, in press) move then to depths 120-350 m and recruit the mature part of population.

Dynamics of size-structure of the northern patch however indicates that it should be recruited by immigration of mature shrimps. Catches in generation, which had been produced in 1996, were less in 1997 than in 1998 (Fig.7 B-C). It is also unknown the fate of elder generations in both 1997 and 1998. Probably this patch is recruited from the unobserved west part while the elder shrimps leave this area and move in back direction. Such migrations are impossible across the southern patches because they are separated by the area of large depths, while in the northern part of the Strait the depths along latitudes are almost constant (Fig.1).

Additional investigations are needed for complete solution of the problem of large-scale migrations across the patches. If the new, unpredictable from previous data, peaks of densities within elder generations appear, existence of such migrations will be confirmed. In this case recommendations to fisheries should be based on evaluation of the stock of the whole population and particular attention to reproductive areas should be paid. If the size-structure would be predicted from data on previous years suggestion of the migrations absence and independent development of patches should be accepted. In this case recommendations should be based on stocks evaluations in each patch.

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References

- BUKIN, S.D. and K.A. ZGUROVSKY. 1988. Distribution patterns, biology and behaviour of humpback shrimp *Pandalus hypsinotus* in the northwestern Sea of Japan. In: Morskiye promyslovye bespozvonochnye. VNIRO, Moscow, p. 108 - 119 (in Russian, English resume).
- BUTLER, T.H. 1964. Growth, reproduction, and distribution of pandalid shrimps in British Columbia. *J. Fish. Res. Board Can.*, **21** (6): 1403-1452.
- BUYANOVSKY, A. I. (in press). On Temporal Variations in the Population of the Humpback Shrimp *Pandalus hypsinotus* (Crustacea, Decapoda) from the Tatar Strait (Sea of Japan). *Zool. Zhurnal* (in Russian, English resume).
- CASSIE, R. M. 1954. Some uses of probability paper in the analysis of size frequency distributions. *Austral. J. Mar. Freshw. Res.*, **5** (3): 513 - 522.
- GALYMZYANOV, K.G. 1994. Seasonal distribution of shrimps in the Tatar Strait based on fisheries data on 1979-1993. In: Rybokhozyaystvennyye issledovaniya v Sakhalino-Kurilskom rayone i sopedelnykh akvatoriyakh. Sakhalinskoye oblastnoye knizhnoye izdatelstvo, Yuzhno-Sakhalinsk, p. 104 - 106 (in Russian).
- HARDING, J. P. 1949. The use of probability paper for graphical analysis of polymodal frequency distributions. *J. Mar. Biol. Assoc. UK*. **28**: 141 - 153.
- IGARASHI, T. 1951. Studies of *Pandalus hypsinotus* Brandt in Funka Bay, Hokkaido. *Bull. Fac. Fish. Hokk. Univ.* **2** (1): 1-9.
- IVANOV, B.G., and D.A. STOLYARENKO. 1990. Unification and computing of field fishery biological analysis (on example of the shrimp *Pandalus borealis*). *Rybnoye khozyaystvo*. (2): 37 - 42 (in Russian).
- KURATA, H. 1981. Pandalid shrimp fisheries of Japan. Proc. Internat. Pandalid Shrimp Symp., Kodiak, Alaska, February 13-15, 1979 (ed. T. Frady). Fairbanks, Alaska. Univ. of Alaska Sea Grant College Program Rep. 81-3., p. 89-159.
- McCRARY, J. A. 1971. Sternal spines as a characteristic for differentiating between females of some Pandalidae. *J. Fish. Res. Board Can.*, **28** (1): 98-100.
- STOLYARENKO, D.A. and B.G. IVANOV. 1988. Spline approximation method of stock density assessments based on results of bottom trawl surveys with reference to deep water shrimp (*Pandalus borealis*) off Spitsbergen. In: Morskiye promyslovye bespozvonochnye. VNIRO, Moscow, p. 108 - 119 (in Russian, English resume)., p. 45 - 70.
- SOKOLOV, V.I. (in press). Remarks on biology of northern, humpback and Japanese shrimps in the Far East seas (Crustacea, Decapoda, Pandalidae). *Zool. Zhurnal*. (in Russian, English resume).
- TABUNKOV V.D. 1982. Ecology, reproductive cycles and reproduction conditions of three species of shrimps of the genera *Pandalus* in the Tatar Strait. *Izvestiya TINRO.*, **106**: 42-53 (in Russian).

Table 1.

Mean carapace length (mm) for different age groups of *P.hypsinotus* from three patches off the eastern part of the Tatar Strait. Patches locations are given on respective details of Fig.3. SE - standard error of mean, N - number of measured shrimps.

No. of age-group	Patch								
	A			B			C		
	Mean	SE	N	Mean	SE	N	Mean	SE	N
I	23.3	0.08	387	22.0	0.07	503	21.9	0.07	401
II	29.1	0.05	1443	27.8	0.07	1128	28.3	0.06	764
III	36.0	0.07	665	35.9	0.14	276	36.3	0.05	984
IV	42.5	0.09	468	41.9	0.22	79	44.5	0.28	52
V	-	-	-	(49.0)	0.35	4	-	-	-

Table 2.

Catches dynamics of *P.hypsinotus* in the eastern part of the Tatar Strait. M - mass, kg per 10 traps, N - number per 10 traps, k - number of samples, SE - standard error of mean.

Latitude (N)	Longitude (E)	Depths (m)	1996			1997			1998		
			M±SE	N±SE	k	M±SE	N±SE	k	M±SE	N±SE	k
49°30'	141°50'	120-200	1.3±0.1	49±7	9	1.4±0.2	52±8	8	0.5±0.1	20±3	10
49°00'	141°20'	200-240	1.9±0.5	64±20	2	1.2±0.1	45±4	32	1.1±0.2	46±6	3
49°00'	141°30'	201-240	1.5±0.1	52±4	26	1.4±0.1	51±2	154	1.4±0.2	48±10	14
48°30'	141°10'	241-260	1.3±0.0	48±2	18	1.4±0.1	49±3	34	1.3±0.2	43±16	2
48°30'	141°25'	120-200	-	-	-	1.4±0.2	76±13	13	1.0±0.4	38±13	3
47°30'	141°05'	201-240	-	-	-	2.0±0.2	89±7	28	1.1±0.2	43±6	6
47°30'	141°30'	241-280	-	-	-	1.1±0.1	49±4	22	0.3	11	1
47°30'	141°05'	200-240	-	-	-	2.3±0.2	114±16	14	2.3±0.2	126±9	35
46°35'	141°25'	241-280	-	-	-	1.3±0.1	77±20	3	2.3±0.2	117±7	52
46°35'	141°45'	281-320	-	-	-	0.5	73	1	2.2±0.2	112±12	23
46°35'	141°10'	240-280	-	-	-	-	-	-	1.1±0.1	46±4	39
46°35'	141°25'	281-320	-	-	-	-	-	-	1.6±0.1	54±4	66
46°35'	141°45'	321-360	-	-	-	-	-	-	1.2±0.2	38±6	20

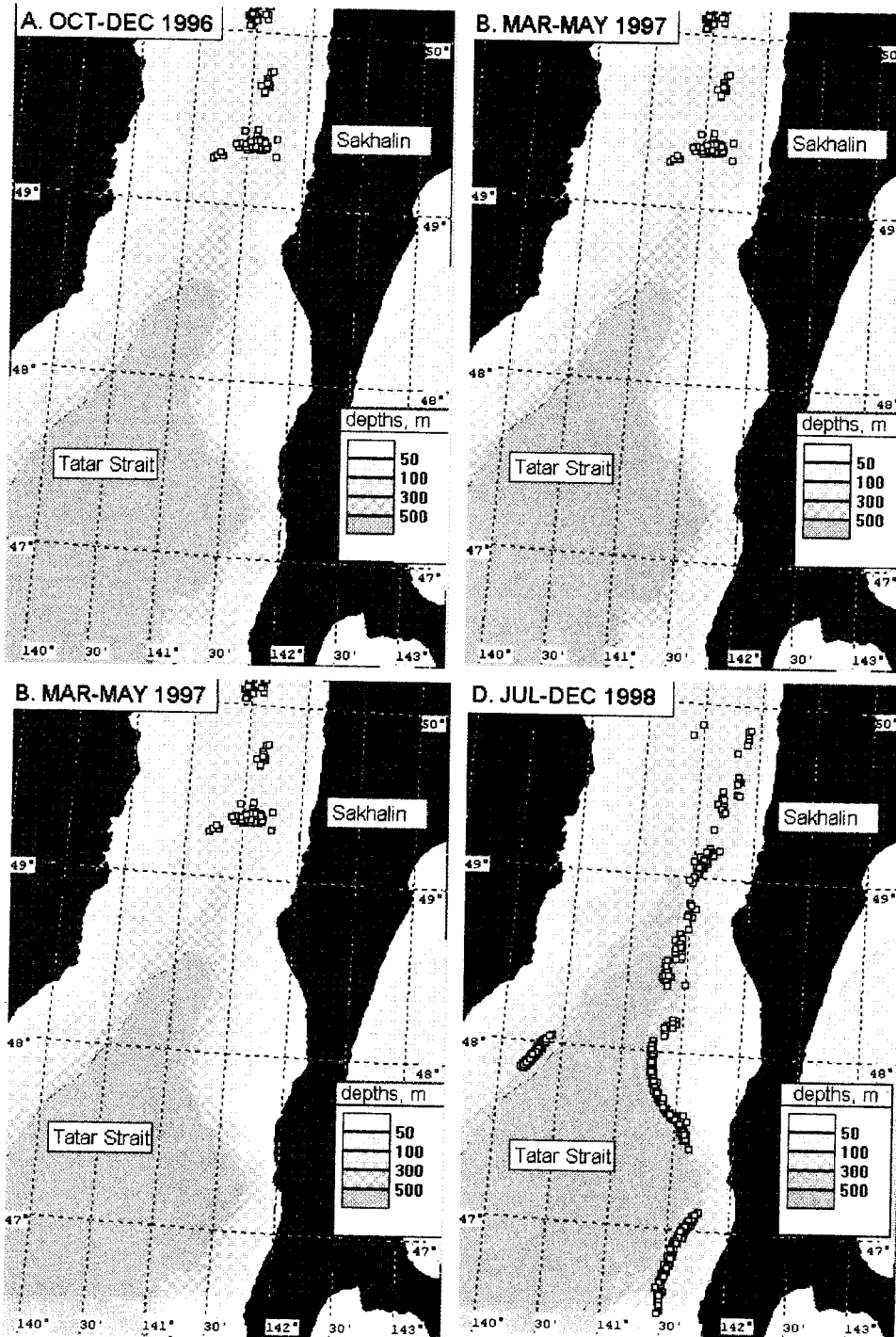


Fig.1. The Tatar Strait. Maps of sampling.

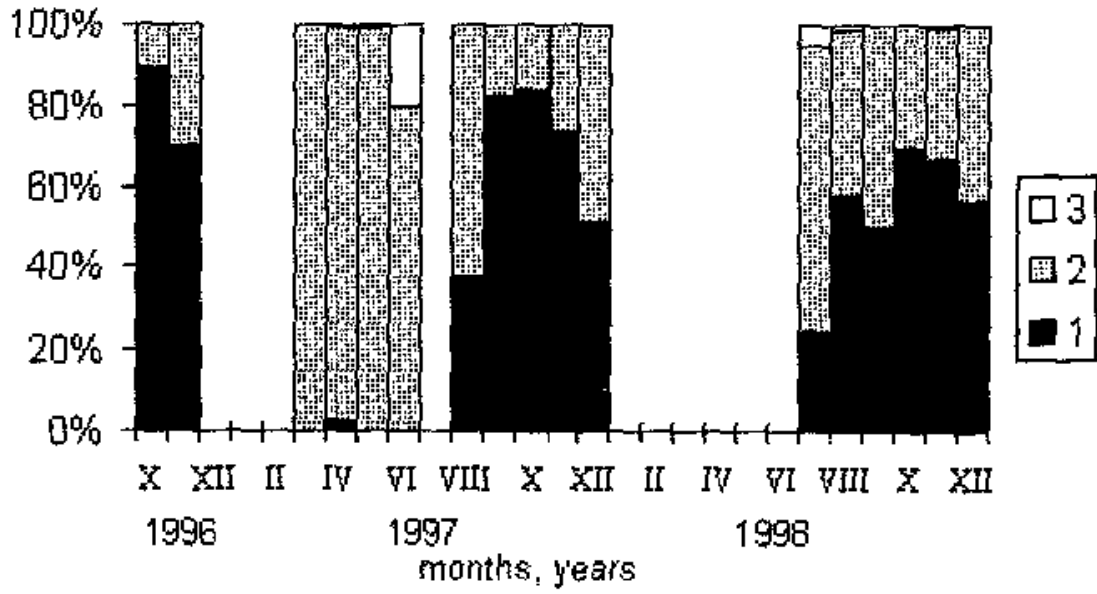
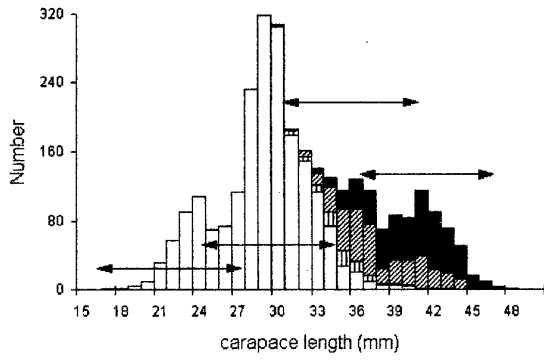
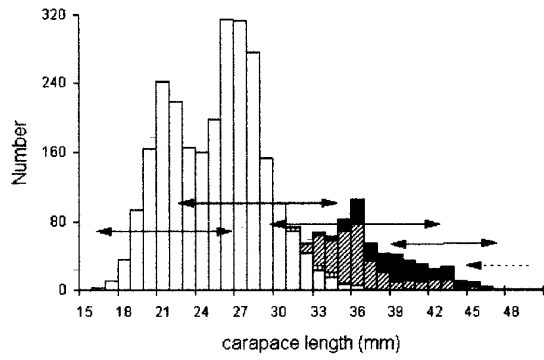


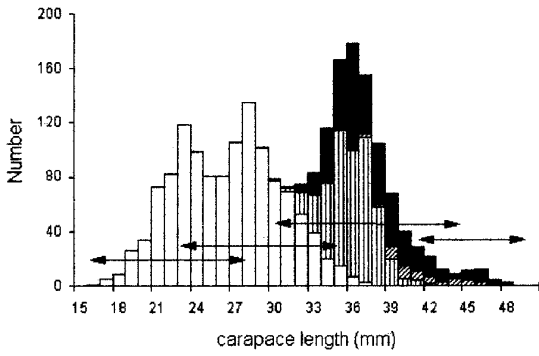
Fig.2. Seasonal changes of roe development for both females and intersexes of *P.hypsinotus* in the Tatar Strait. Legend values: 1 - inner roe; 2 -outer eggs; 3 - larvae released.



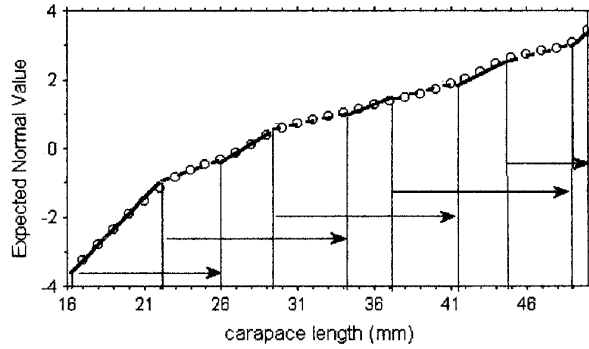
**A. 46°35' - 47°10' N, 141°20' - 141°50' E
20 AUG - 28 SEP 1998
Depths 240 - 360 m. Samples 88.**



**B. 47°25' - 48°00' N, 141°10' - 141°40' E
30 JUL - 15 AUG 1998.
Depths 190-350 m. Samples 77.**



**C. 48°45' - 49°43' N, 141°25' - 141°55' E
18 NOV - 19 DEC 1998
Depths 130 - 260 m. Samples 53.**



D. The same as (B)

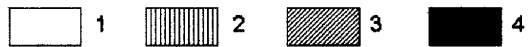


Fig.3. Size and sexual structures of *P.hypsinotus* catches in 3 patches in the Tatar Strait (A - C) and separation of age groups on normal probability plot (D). Legend values: 1 - males, 2 - intersexes, 3 - females with outer roe, 4 - females with inner roe and without sternal spines. Arrows point ranges of age groups.

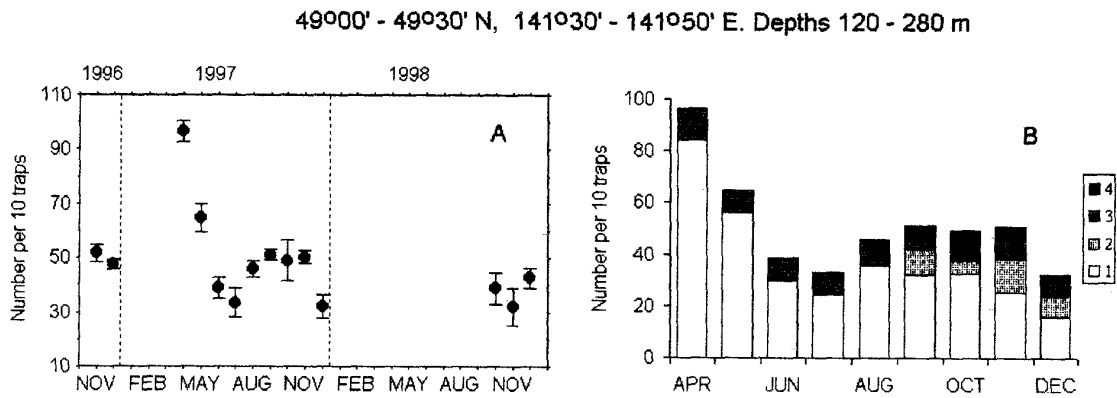


Fig.4. Annual dynamics of *P. hypsinotus* catches in the north-eastern part of the Tatar Strait: A - all shrimps, whiskers show SE of means; B - sexual groups in 1997: 1 - males, 2 - intersexes, 3 - females with outer eggs, 4 - females with inner roe without sternal spines.

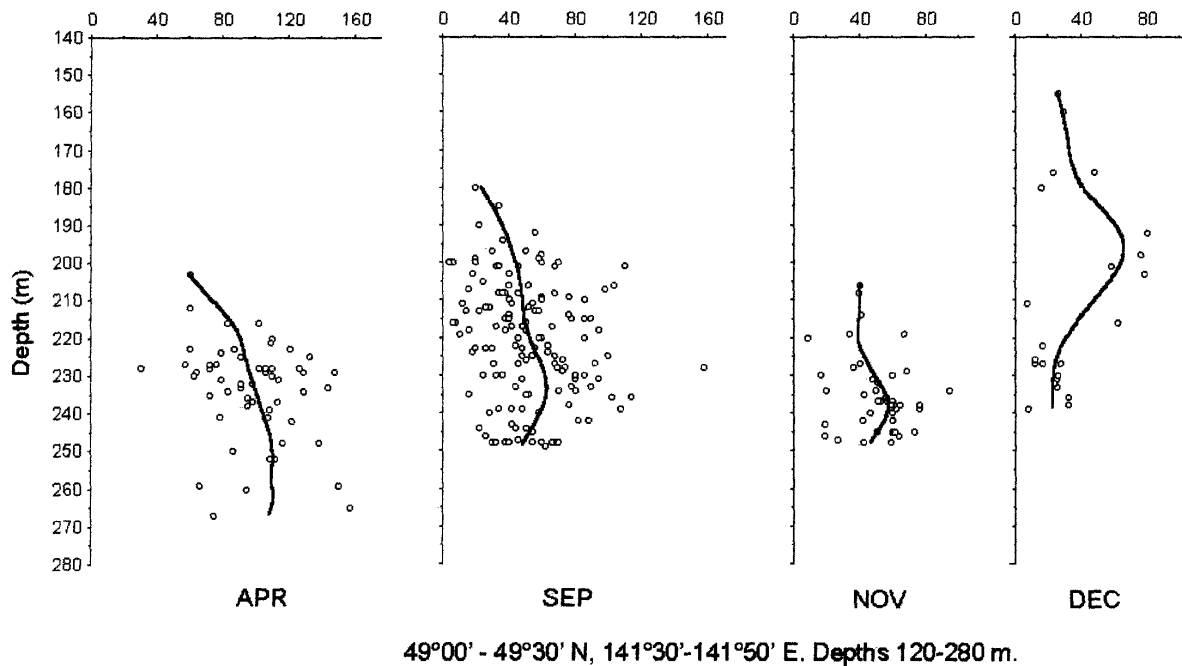


Fig.5. Temporal changes in bathymetric distribution of *P. hypsinotus* catches in the north-eastern part of the Tatar Strait. Curves were fitted by least squares.

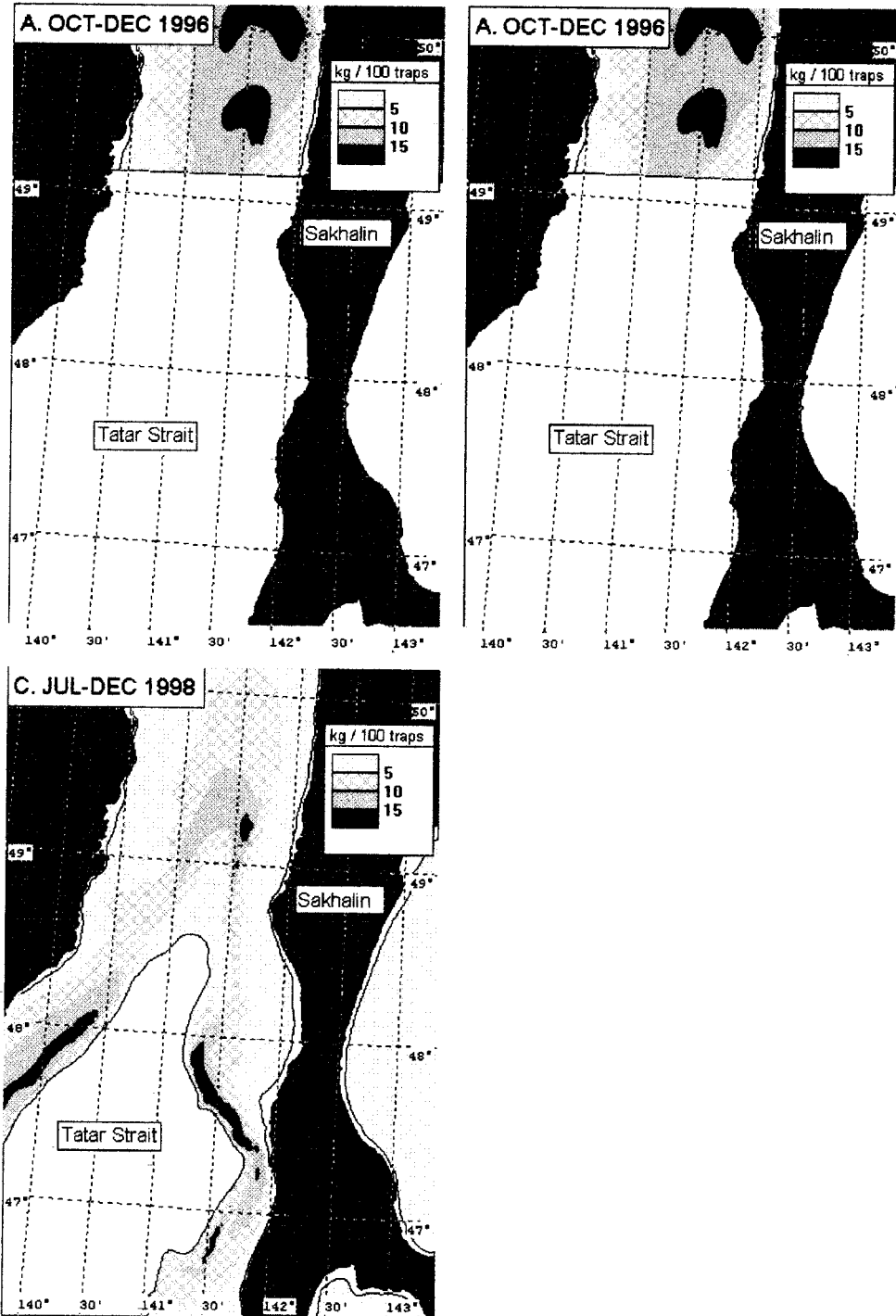


Fig.6. Extrapolated map of spatial distribution of *P. hypsinotus* catches in the Tatar Strait.

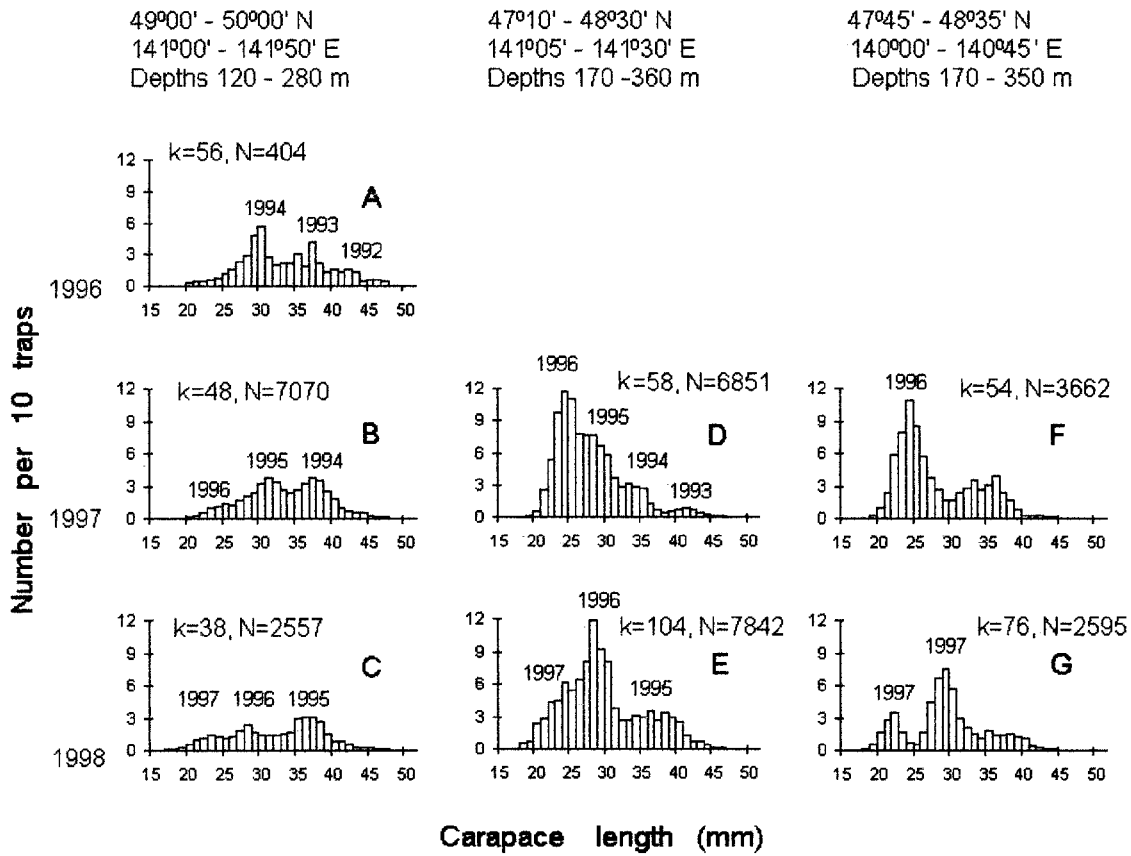


Fig.7. Dynamics of *P.hypsinotus* size-structure in different patches. k - number of samples, N - number of measured shrimps. Values on figures show the years of generations appearance.