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Composition and Structure of Macrofouling Communities on Ocean-going Ships in the Far East Sea Basin

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Abstract : Species composition and community structure of the fouling found on the hulls of 28 ships traveling through 6 main shipping routes (SR) in the Far East Sea Basin were analyzed using statistical methods. Samples obtained during 1976-1990 expeditions of the Institute of Marine Biology were used for the analyses. These samples were taken from the ships anchored in the harbor by SCUBA diving and in dry-docks of the Vladivostok ship-repairing yard. Similar composition of the fouling communities occurred on the ships travelling the same SR. In five cases, fouling was dominated by different Cirripedia communities. And, in one case, a community of the mussel *Mytilus trossulus* was found. In most cases the results of the factor analyses showed extremely low level of the relationships among different animals and algal species in fouling communities. Each ocean-going ship had an original structure of the fouling. Spatially disconnected animal associations of tropical and boreal origin may simultaneously coexist at the same ship. This paper testified to the originality of the zone of anthropogenic substrata as a benthos concentrator in the pelagic regions of the world ocean. The fouling from different zones showed that each zone possesses peculiar features and regularities of the composition and relationships between organisms dwelling here.

Key words : fouling, ship, shipping route, community, barnacle, mussel, factor analysis.

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1. Introduction

An intensive work on coastal and marine ship macrofouling (hereinafter: fouling) was conducted in Russia (USSR) since 1950-1960 (Tarasov 1959, 1961, 1962; Zevina 1961, 1962, 1972; Rudyakova 1958, 1967 a, 1967 b). The institute of Marine Biology initiated the study on the ship fouling in 1975. Fouling samples from approximately 600 ships operating in different modes in the Far East Seas were collected. The succession patterns of the fouling were followed up on a selected ship with a certain route. The results of the investigations were published in several papers (Kudryashov 1980, 1981; Zvyagintsev 1984; Zvyagintsev and Mikhailov 1978; Zvyagintsev *et al.* 1982; Mikhailov 1989).

Similar to benthos analyses in fouling, we may distinguish communities according to the dominant organisms (Petersen 1915; Gilsen 1930; Vorobbev 1949; Mokievskii 1960; Rudyakova 1981). Unlike benthos, the fouling communities, as a rule, show a clear physiognomic pattern. Discerning the fouling communities on ships is an easy procedure because only 1-2 species usually prevail, and the portion of secondary and other organisms is always negligible (Rudyakova 1981).

The duration of a ship floating is usually limited by interdocking period (usually by one navigation, and rarely by 1-2 year or more) which also simplifies the investigation of fouling. Development of the fouling communities is mainly controlled by abiotic (including anthropogenic) factors that corresponds to the concept of individuality for benthos (Gleason 1926). Sanders (1968) proposed the terms physically controlled

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and biologically balanced communities, and considered that these types of communities are their extreme variants. According to the Sanders terminology, the ship fouling might be related to the physically controlled communities, which are usual occurrances at a shoal of boreal seas.

Species composition, distribution and abundance of fouling organisms are known to be influenced by ship speed and, as a whole, by hydrodynamics of the ship hull (Igic 1968; Zvyagintsev and Mikhailov 1978; Mikhailov 1985 a, b; Mikhailov and Blinov 1981; Revin 1981, Railkin 1998). However, there are very few information on the relationships among organisms forming ship-fouling communities.

The goal of this work is to study the composition of fouling organisms and the relationships between main fouling animals and algal species forming these communities on the ships of the Far East Sea Basin.

2. Materials and methods

The materials used here were collected during the expeditions carried out by the Institute of Marine Biology of Far East Division of Russian Academy of Sciences in 1976-1990. Most of the samples were taken from the ships during their anchorage by SCUBA diving according to the methods and scheme (Fig. 1) worked out in the Institute of Marine Biology (Zvyagintsev and Mikhailov 1980). Some other ships were examined in dry-docks by similar scheme. In total, 28 ships were studied and 426 quantitative and 28 qualitative samples were taken and treated for analyses.

Algae and animals collected were identified to species level, weighed up to 0.001 g accuracy (wet weight), and for solitary animals the settlement density was determined. Communities were distinguished according to the biomass of dominant species.

In the case of very great number of the operation modes (running regime, alternation between sailing and anchorage, duration and times of navigation length of sail, etc.), and the variety of constructions and protective coatings of the hulls, it is rather difficult to receive adequate data that allow to reveal the interrelations of organisms forming fouling communities. To obtain comparable materials, we used the data from the ships operated during one navigation (usually 6-8 months) along the same SR. Here we present the results from 28 ships of following SR: Bering Sea route (7 ships), Russia - West Japan route (5), Russia - East Japan route (4), Russia - South Japan route (3), Russia - Vietnam route (6), and Russia - Cuba route (3).

For statistical treatment; we used standard procedures and tests offered by "STATISTICA 5.1" software (STATISTICA 1996). To analyze the relationships

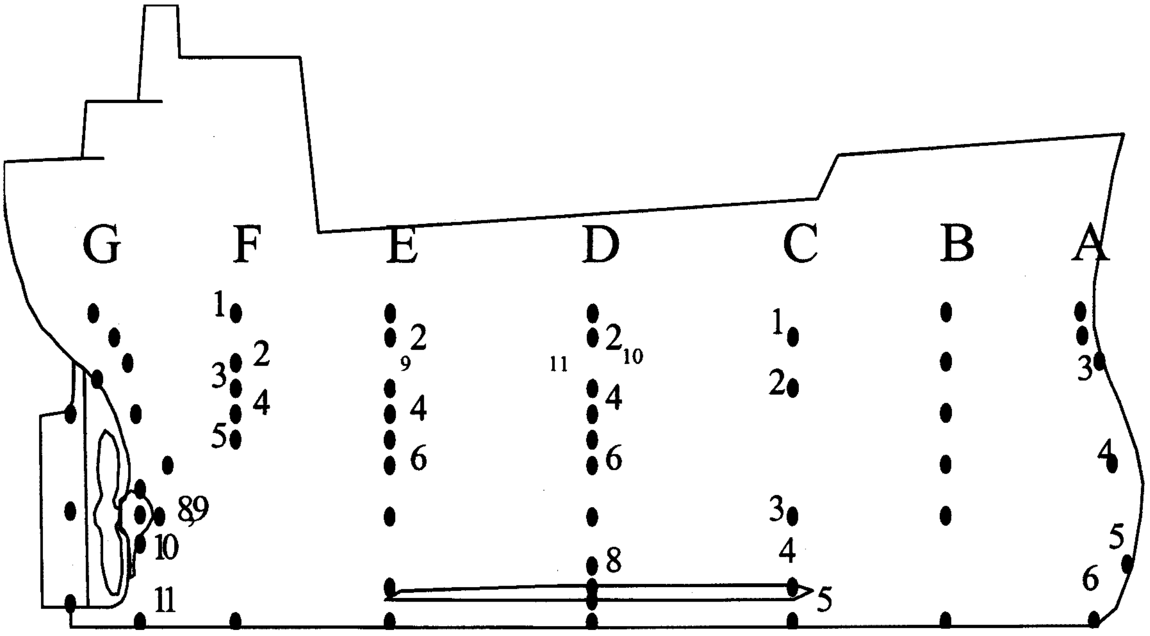

Fig. 1. Sampling of scheme of fouling organisms on the ship hull (points are sampling locations).

Table 1. Some characteristics of the studied ships and fouling communities.

Ship's name	SR	DU	VEL	N_{SA}	N_{SP}	B_T ± SD	B_{AG} ± SD	B_{AN} ± SD	N_F
Ivan Babushkin	B	8	14.0	25	6	2341.6 ±1487.0	871.5 ±1214.9	1470.2 ±1307.0	3.0
Belorussia	B	10	11.5	25	22	8028.8 ±7223.3	31.7 ±63.1	7997.1 ±7237.7	9.5
Chukotka	B	10	14.0	23	25	6399.8 ±5040.3	176.5 ±457.6	6046.8 ±5190.6	11.0
Kozyrevsk	B	9	14.6	14	14	3178.9 ±4584.6	357.4 ±506.4	2821.6 ±4458.6	5.5
Rzhev	B	15	16.9	24	19	1012.3 ±1580.5	78.6 ±154.2	933.7 ±1617.8	8.0
Yakov Sverdlov	B	9	14.0	17	12	1100.8 ±828.0	495.3 ±553.9	605.5 ±946.9	6.0
Uritskii	B	14	18.2	7	8	2339.3 ±4341.4	64.2 ±165.7	2275.1 ±4373.0	4.0
Dalny-2	RSJ	6	14.1	6	11	1251.9 ±392.8	263.1 ±464.2	988.8 ±624.0	3.0
Galich	RSJ	6	12.0	29	31	1516.1 ±880.9	140.9 ±358.5	1375.2 ±986.6	11.0
Undzha	RSJ	6	15.0	6	16	1477.1 ±893.3	264.7 ±206.9	1212.3 ±824.0	3.5
Petropavlovsk-Kam.	REJ	10	11.5	12	12	374.8 ±473.6	111.3 ±171.5	263.5 ±446.8	5.0
Primorles	REJ	6	16.0	9	6	220.4 ±138.3	44.7 ±86.1	175.7 ±127.0	3.0
Suhona	REJ	7	12.4	6	10	1439.1 ±750.8	8.7 ±21.2	1430.4 ±760.4	3.5
Ul'yanovsk	REJ	10	11.5	9	11	1091.1 ±2138.1	18.4 ±31.7	1072.6 ±2128.4	4.0
Andoma	RK	6	16.0	24	14	1737.6 ±2518.1	79.4 ±234.3	1658.2 ±2552.8	6.0
Pripyat	RK	6	16.0	18	9	1142.9 ±965.3	34.8 ±147.8	1108.0 ±995.8	4.5
Vorkuta	RK	3	16.0	18	8	177.5 ±282.3	7.1 ±29.9	170.3 ±284.7	4.5
Dalny	RV	7	14.1	22	6	2539.2 ±1456.3	-	2539.2 ±1456.3	3.5
Ohaneft	RV	7	16.4	12	9	643.3 ±619.1	18.5 ±60.7	624.8 ±623.7	4.0
Larisa Reisner	RV	5	19.3	10	6	491.2 ±480.0	6.9 ±10.0	484.3 ±479.1	3.5
Nikolai Semashko	RV	5	17.2	24	7	781.7 ±498.0	3.4 ±14.7	778.3 ±500.7	3.5
Svirsk	RV	8	14.0	6	7	424.1 ±572.4	-	424.1 ±572.4	2.5
Volgograd	RV			12	10	422.0 ±232.5	-	422.0 ±232.5	4.0
Donbass	RWJ	8	11.5	12	32	2051.0 ±1939.5	8.6 ±18.9	2042.4 ±1948.3	5.0
Pioner Rossii	RWJ	8	16.5	7	15	3879.7 ±5735.7	-	3879.7 ±5735.7	4.0
Bikin	RWJ	8	14.1	7	19	1820.7 ±1041.2	401.1 ±632.8	1419.6 ±1153.0	3.5
Pyatigorsk	RWJ	8	16.9	44	42	1552.8 ±2485.8	27.3 ±63.5	1525.5 ±2478.1	15.0
Chirikov	RWJ	8	11.5	20	20	2952.7 ±4298.7	53.5 ±146.2	2899.1 ±4332.1	8.0

SR - sea routes: B - Bering Sea, REJ - Russia - East Japan, RSJ - Russia - South Japan, RWJ - Russia - West Japan, RK - Russia - Cuba, RV - Russia - Vietnam; DU - route duration, months; VEL - speed in ballast, knots; N - number: SA - samples, SP - species, F - factors; B - averaged biomass, g/m^2 (T - total, AG -algae, AN - animals); SD - standard deviation.

among fouling organisms, we applied the factor analyses (principal components and maximum likelihood methods). To simplify the factor structure and to easily derive interpreted solutions, different methods of axes rotation, the varimax, the quartimax, etc., were used (Afifi and Eisen 1982; Kim *et al.* 1989). Selection of factor numbers was made by Kaiser criterion and scree plot test, and, if possible, by statistical goodness of fit test (if a selected factor solution is obtained by the principal components method and that revealed by the maximum likelihood one may coincide in main features). Factor orthogonalities were tested by a hierarchical analysis of the oblique factors.

3. Results

The ships which were examined during this studyperiod were different from each other in construction, duration of the ship operation prior to sampling and, naturally, in SR features, which are characterized by different duration of transitions and anchorage in different ports, different regions of float, anchorages in rivers, etc. In result, the communities of similar taxonomic composition were formed on the ships of the same SRs. Below we give brief descriptions of these communities for the ships of the selected SRs. Different characteristics of these ships and some features of their fouling are shown in Table 1.

On the ships of the Bering Sea route connecting Vladivostok and Nakhodka ports with those of Kamchatka and Russian coast of the Bering Sea, a community of *Balanus crenatus* was recorded. It was composed of 13 algal and 29 animal species, and 14 species were motile forms. *B. crenatus*. The dominant species, was the majority of the total biomass (2930 g/m^2). Biomass of typical species, *Ectocarpus confervoides* (brown algae), *Mytilus trossulus*, and *Semibalanus cariosus* was similar, and varied between 350 and 405 g/m^2. Portions of other species were by 1-2 orders lower.

The *Mytilus trossulus* community was typical for the ships travelling the Russia - West Japan route connecting Vladivostok and Nakhodka ports with those of Hokkaido and the northwestern Honshu Islands, the Otaru, the Hakodate, the Niigata and the Aomori. This community included 7 algal and 42 animal species; 11 of them were motile forms. More than a half of total biomass (2046 g/m^2) was made up by the mussel *M. trossulus* (1218 g/m^2). Typical species showed similar biomass: *Balanus amphitrite* averaged 232 g/m^2, *Balanus improvisus* made up 106 g/m^2, and *Crassostrea gigas* was 101 g/m^2. These species were found together with the dominant organism in the fouling layer of all ships of this route. Some barnacle species, *Megabalanus intinnabulum, M. rosa, Balanus trigonus, B. eburneus, B. albicostatus,* were typical for Japanese coastal waters only. The abundance of the members of pelagic fouling goose-neck barnacles *Lepas anatifera* and *Conchoderma auritum,* was low due to ships short duration in open water floating.

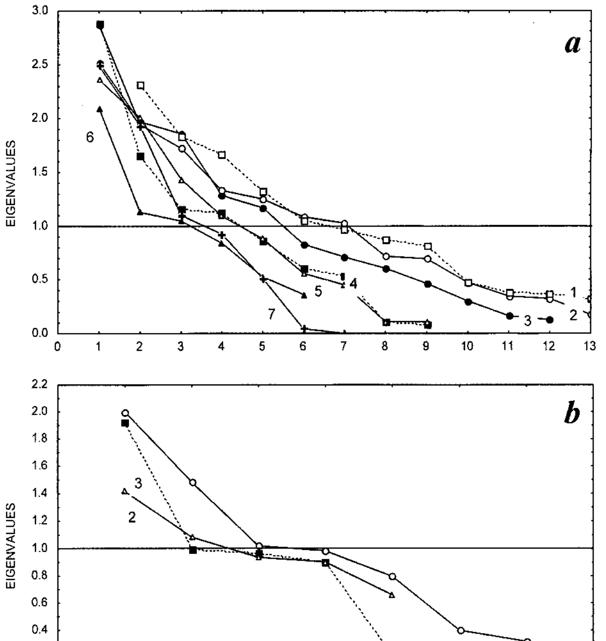

Fig. 2. Results of scree plot test for factor solutions of separate (a) and several (b) ships. For a: 1 - "Byelorussia", 2 - "Chukotka", 3 - "Galich", 4 - "Andoma", 5 - "Ochaneft", 6 - "Dalny", 7 - "Semashko"; for b: 1 - five ships of Bering Sea SR, 2 - three ships of the Russia-South-Japan SR, 3 - three ships of the Russia-Cuba SR; .the value of Kaiser criterion is designated by horizontal line.

The *B. improvisus* community was found on the ships of the Russia - East Japan route connecting the East Sea Russian ports with three main Japan port complexes, the Keihin (ports of Yokohama, Tokyo, and Chiba in Tokyo Bay), the Tokai (port of Nagoya in Ise Bay), and the Hanshin (ports of Osaka and Kobe in Osaka Bay). It consisted of 5 algal and 20 animal species. The biomass of dominant species comprised 60 % of the total biomass (753 g/m^2). Typical species were *B. trigonus* (90 g/m^2), *M. trossulus*(59 g/m^2), and *Ulva fenestrata*(50 g/m^2). The fouling from this SR included warm-water species *B. trigonus, B. albicostatus, M. tintinnabulum,* and *M. rosa,* which were typical for the East Japan ports. Members of the pelagic fouling organisms were not found.

The *B. amphitrite* community was recorded on the ships of the Russia - South Japan route connecting the East Sea Russian ports with the South Japan port complex Kanmon (ports of Yahata, Nagasaki, Kagoshima, and Shimonoseki). The community included 5 algal and 30 animal species; 8 of them were motile forms. The dominant species *B. amphitrite,* comprised about 50 % of the total biomass (1404 g/m^2). Typical species were the colonial ascidian *Ciona intestinalis* (142 g/m^2), *U. fenestrata* (107 g/m^2), *B. improvisus* (105 g/m^2), sedentarian polychaete *Hydroides elegans* (92 g/m^2), and *B. eburneus* (81 g/m^2). In this community, we also found the species which exist in the Japanese ports only. They were *B. albicostatus, B. trigonus,* and polychaete *Nereis multignatha.* Only one pelagic fouling organism, *Lepas*

Table 2. Some quantitative characteristics of the fouling community of the motor-ship "Galich".

Species	P	B ±SD	A ±SD	I_w*	$\sqrt{PB}$	R	p
E. linza	37.9	38.8 ±125.7	-	-	38.4	-0.193	0.298
U. fenestrata	31.0	90.9 ±314.6	-	-	53.1	0.012	0.949
O. longissima	41.4	1.1 ±2.1	-	-	6.8	0.156	0.402
H. elegans	100.0	157.3 ±157.7	-	-	125.4	-0.040	0.831
N. pelagica	65.5	5.3 ±15.4	406.9 ±509.9	**324.7**	18.7	**0.383**	0.033
P. lymicola	31.0	1.9 ±4.2	-	4.2	7.7	0.260	0.157
B. albicostatus	65.5	35.0 ±49.1	420.7 ±507.4	**348.8**	47.9	**0.445**	0.012
B. amphitrite	100.0	667.3 ±600.8	3751.7 ±3735.4	**3768.1**	258.3	**0.482**	0.006
B. improvisus	93.1	87.1 ±105.2	1072.4 ±1307.9	**879.3**	90.1	**0.555**	0.001
B. trigonus	55.2	7.8 ±14.1	165.5 ±210.9	**129.9**	20.8	0.296	0.106
B. eburneus	62.1	110.6 ±148.3	641.4 ±1011.2	**406.8**	82.9	**0.422**	0.018
B. crenatus	34.5	18.3 ±77.7	165.5 ±339.4	**80.7**	25.1	**0.574**	0.001
S. cariosus	20.7	4.0 ±14.9	55.2 ±145.4	20.9	9.1	0.123	0.510
Ch. dalli	24.1	0.9 ±2.1	44.8 ±105.5	19.0	4.5	-0.110	0.556
J. falcata	86.2	2.3 ±3.6	1048.3 ±2318.3	**474.0**	14.2	**0.409**	0.023
M. trosssulus	65.5	40.2 ±197.2	1848.3 ±7019.1	**486.7**	51.3	**0.550**	0.001
C. intestinalis	24.1	234.2 ±473.3	-	-	75.2	**0.683**	0.000
Other	6.9	14.7 ±34.0	-	-	10.1	-0.133	0.476

A - settlement density, specimens/m^2; - frequency, %; I_w - dispersion index (after Elliott 1977; significantly contagious distributions are boldfaced); R - correlation coefficients between total biomass and that of each animal or algae species (significant coefficients are boldfaced); - probability. Other designations are as in table 1.

anatifera, was found with low abundance.

The *Balanus reticulatus* community was observed on the ships of the Russia -Vietnam route connecting the main East Sea Russian ports, Vladivostok and Nakhodka, with Vietnamese parts, the Haiphong and Ho Chi Minh, located in river areas. This community included 18 animal and one algal species. The dominant species comprised 83.8 % of the total biomass (914 g/m^2). The biomass of the secondary species were one order lower. The community contained the pelagic foulers *L. anatifera*, *C. auritum*, and *Conchoderma virgatum*. Only motile form was the polychaete *Typosyllis* sp. found in an empty barnacle shell.

The *B. eburneus* community was typical for the transport fleet ships at the Russia - Cuba route. One algal and 16 animal species made up of the community structure. Subdominant species were *B. amphitrite* and polychaete *Serpula* sp. An average biomass reached about 900 g/m^2 after the float. The fouling was mainly formed in Cuban waters, and a member of the pelagic fouling organisms, *L. anatifera*, were adhere to the ships during transitions.

Naturally, the abundance and composition of fouling community depend not only on general characteristics of SR, but also on the concrete peculiarities and operation regime of each ship. For example, the number of species was negatively related with ship floating speed (correlation coefficient $R = -0.513$, $p < 0.05$). The total biomass, biomass of all animals and that of attached animals, although very weakly, were positively correlated with the duration of ship operation in the water. For the ships of Bering Sea and Russia - Vietnam SRs, the total biomass and biomass of animals and algae were reduced with ship floating speed increase ($R = -0.7\sim0.9$). Unfortunately, a small sample number did not allow us to judge on the actual force of interrelationship among these characteristics.

The results of the factor analyse on the fouling communities showed extremely low level of the relationships between biomass (and, for solitary animals, between settlement density) of different animal and algal species in most cases (Fig. 2). A strong correla-

Table 3. Factor loadings, total and percentage variance explained for biomass of some animal species occurred on the motor-ship "Galich". Extraction method - principal components; factor rotation - quartimax raw.

Species	Factor 1	Factor 2
N. pelagica	0.512	0.330
P. lymicola	0.655	0.046
B. albicostatus	0.061	0.666
B. amphitrite	-0.253	0.723
B. improvisus	0.351	0.439
B. trigonus	0.676	-0.235
B. eburneus	0.546	0.319
B. crenatus	0.903	-0.088
J. falcata	0.145	0.605
M. trossulus	0.871	-0.124
C. intestinalis	0.759	0.297
Explained variance	3.807	1.905
% of total variance explained	0.346	0.173

Table 4. Results of the goodness of fit test (whether all off-diagonal elements in the residual correlation matrix are equal to 0).

Ship's name	X^2	df	p
Galich	90.9	34	0.000
Pyatigorsk	81.0	52	0.006

Table 5. Correlation between oblique factors (clusters of variables with unique loadings). Galich - above diagonal, Pyatigorsk - under diagonal.

Clusters	1	2	3
1	1.000	0.233	-
2	0.081	1.000	-
3	0.228	0.376	1.000

tion between factor number and amount of fouling species (R=0.838, $p < 0.000$) testified to this assertion. Therefore, the distribution pattern of each species seemed to be original, and each species, at least for algae and attached animals, possessed the proper preferendum areas. Any transformations of the primary data ($\sqrt{1+X}$, Log(1+X), etc.) only occasionally allowed to increase the correlation coefficients between the characteristics of separate species abundance and, as a whole, such procedures rendered negative influence. The factor occurrences of similar structures, i.e. factors joining the same species (naturally, For the same or adjacent SRs), were rarely observed. Only on the ships of the Bering Sea and the Russia - East Japan SRs, the factors including *B. crenatus* and *M. trossulus,* were frequently found (approximately in 60 % of the ships studied).

The relationship between algal and faunal species based on the examples of the motor-ships "Galich" and "Pyatigorsk" showed considerable difference in the composition of the fouling communities and fouling organism distribution (dominant species were *B. amphitrite* and *M. trossulus,* accordingly). Preliminary data analyses showed that many species were only occasionally found in samples. Therefore, only the species occurring more than 20 % of samples were used in analyses. The remaining species were summarized and their biomass was further considered as a biomass of the "rest" organisms (in average, their portions in total biomass made up approximately 1.6 % and 2.9 % on Galich and Pyatigorsk, correspondingly).

On the hull of Galich, the maximal frequency, as well as other characteristics of abundance, was found in the dominant species of *B. amphitritae,* and minimal one was *Chthamalus dalli* (Table 2). Other species - *Hydroides elegans, Ciona interstinalis, B. improvisus, B. eburneus* - were typical in this community, but their biomass were 2.1-3.4 times lower than that of the dominant species. Distribution of the biomass was noticeably asymmetrical in all species, and showed clear right "tails", that itself testified to the contiguous pattern of animals and algae distribution on the surface of the ship hull. Distribution of attached solitary animals was also significantly contiguous in most cases . It should be emphasized that the significant correlation coefficients between total biomass and that of separate species were rarely observed in animals and never found in alga.Factor analyses were carried out in 4 main variants:

- For animal and algal species, whose frequency exceeded 20 %;
- For animal species, whose frequency exceeded 20 % (green algae *U. fenestrata* and *Enteromorpha linza* showed two factors at a significant level including only these algae separately without noticeable linkage with other species and with loadings close to 1);
- Only for animals, whose biomass significantly and positively correlated with total biomass;
- *Polydora lymicola* and *B. trigonus,* added to the organ-

Table 6. Some quantitative characteristics of the fouling community of the motor-ship "Pyatigorsk."

Species	P	B ±SD	A ±SD	I_w*	$\sqrt{PB}$	R	p
U. fenestrata	34.1	17.4 ±43.3	-	-	24.4	0.296	0.051
H. elegans	75.0	5.7 ±8.5	-	-	20.7	0.047	0.761
N. pelagica	47.7	3.3 ±5.9	352.4 ±575.6	**940.3**	12.6	**0.516**	0.000
B. albicostatus	36.4	21.8 ±62.0	815.9 ±3175.1	**12356.0**	28.2	-0.088	0.570
B. amphitrite	95.5	233.4 ±610.3	4559.1 ±10506.5	**24212.6**	149.3	0.202	0.188
B. eburneus	40.9	36.1 ±63.8	554.5 ±1163.3	**2440.3**	38.4	0.117	0.448
B. improvisus	86.4	72.9 ±135.9	1513.6 ±2114.4	**2953.5**	79.4	0.221	0.150
B. trigonus	54.5	73.0 ±87.6	431.8 ±799.1	**1478.6**	63.1	0.196	0.203
M. tintinnabulum	38.6	163.6 ±507.7	247.7 ±871.4	**3065.1**	79.5	**0.508**	0.000
S. cariosus	20.5	10.5 ±50.8	88.6 ±212.6	**510.1**	14.6	**0.431**	0.003
J. falcata	31.8	0.1 ±0.1	59.1 ±120.7	**246.5**	1.3	-0.159	0.304
C. gigas	31.8	123.9 ±303.0	165.9 ±619.1	**2309.9**	62.8	**0.449**	0.002
M. trossulus	86.4	739.7 ±2086.5	8961.6 ±11400.6	**14503.3**	252.8	**0.884**	0.000
C. seurati	50.0	0.2 ±0.5	-	-	3.5	**0.372**	0.013
C. pallasiana	54.5	3.7 ±8.6	-	-	14.2	0.102	0.512
H. perforata	22.7	0.3 ±0.8	-	-	2.4	0.071	0.648
S. unicornis	20.5	0.5 ±1.6	-	-	3.2	0.049	0.750
Other	5.9	46.6 ±102.1	-	-	16.6	0.147	0.340

A - settlement density, specimens/m^2; - frequency, %; I_w - dispersion index (after Elliott 1977; significantly contagious distributions are boldfaced); R - correlation coefficients between total biomass and that of each animal or algae species (significant coefficients are boldfaced); - probability. Other designations are as in table 1.

isms used in variant 3. For these species the correlation between their biomass and total biomass was close to significant.

Taking into account Kaiser criterion, scree plot and goodness-of-fit tests, and also the results of the hierarchical factor analyses (minimal correlation coefficients between clusters of primary variables or oblique factors), the most acceptable and easily interpreted solution was that of two factors for variant 4 (Table 3-5). The revealed factors described almost 52 % of the variance of species biomass, and two spatially disconnected animal associations, the *B. crenatus+M. trossulus+C. interstinalis* (accompanying species were *B. eburneus* and polychaete *Nereis pelagica*) and *B. amphitrite* (accompanying species were *B. albicostatus* and isopode *Jassa falcata*), were clearly distinguished (Fig. 3).

According to the biomass, the first association was the most abundant in the stern part of the ship, and the second association was most abundant in the bow part and in the midsection. Also, its separate local spot was situated at the sternpost near the waterline. It should be underlined that the loadings on the species biomass , even those included in the associations distinguished here, mostly made up less than 0.7, i.e. revealed factors described less than 50 % of the variance of these variables.

For the Pyatigorsk, the biomass of dominant species *M. trossulus* was thrice higher than that of the secondary species *B. amphitrite*. And, the settlement density of the first species was almost twice greater than that of the second species (Table 6). Other typical species of this community were *M. tintinnabulum, B. improvisus, B. trigonus,* and *C. gigas*. The significant correlations between total biomass and biomass of separate animal and algal species were observed here much less often than on the Galich. The solution with 3 factors for the animals with the frequency exceeding 20 % (without *H. elegans* whose distribution, as well as alga *U. fenestrata,* was extremely out of ordinarly and practically did not match with the distributions of other species) was the most acceptable and easily interpreted (Table 4, 5, 7). According to this solution, we may rather satisfactorily

Table 7. Factor loadings, total and percentage variance explained for biomass of some animal species occurred on the motor-ship "Pyatigorsk". Extraction method - principal components; factor rotation - varimax raw.

Species	1	2	3
N. pelagica	0.220	-0.054	0.774
B. albicostatus	-0.080	-0.142	-0.285
B. amphitrite	0.101	-0.126	-0.204
B. eburneus	0.631	0.327	-0.409
B. improvisus	0.669	-0.215	0.083
B. tinr	0.852	-0.062	0.410
B. trigonus	0.741	0.267	-0.257
S. cariosus	0.870	-0.032	0.206
C. gigas	0.355	0.266	0.649
M. trossulus	-0.015	0.111	0.623
C. seurati	-0.008	0.261	0.066
C. pallasiana	-0.143	0.696	0.231
H. perforata	0.078	0.560	0.169
S. unicornis	0.085	0.852	-0.076
Explained variance	3.103	1.943	2.074
% of total variance explained	0.222	0.139	0 .148

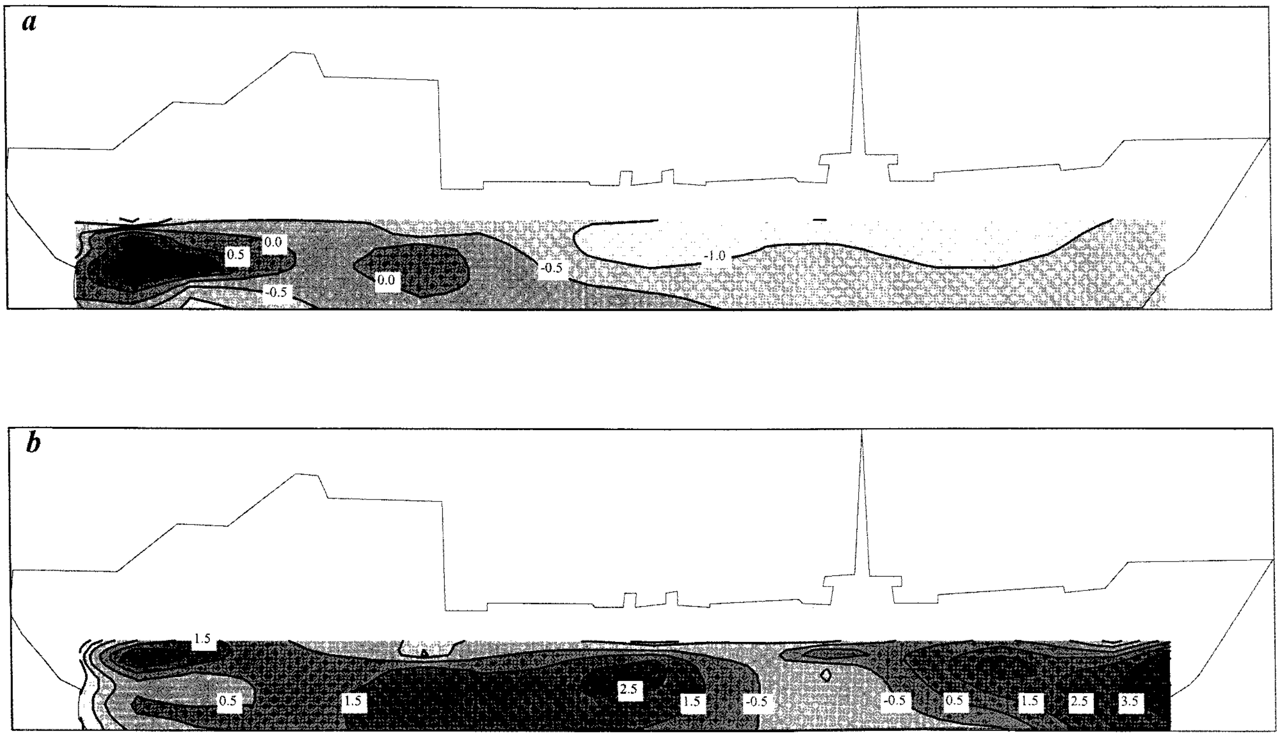

Fig. 3. Distribution of the factor values on the hull of the motor-ship "Galich" (a, b are the 1st and 2nd factors from the table 3, correspondingly)

distinguish three animal associations on the ship hull. The first association included the barnacles *B. eburneus, B. improvisus, B. trigonus, M. tintinnabulum,* and *S. cariosus;* the second association was the bryozoans *Cryptosula pallasiana, Hippoporina perforata,* and *Schizoporella unicornis;* and, the third association was the bivalve mollusks *M. trossulus, C. gigas* and the polychaete *Nereis pelagica.* However, when compared against the Galich, we did not observe any clear spatial dissociation, especially in the case of the last two associations (Fig. 4). Although their distribution patterns should not be determined as regular, these associations were considerably overlapped in the range of mean factor values, i.e. as if they were imposed against each other. As well as on the Galich, factor loadings for the species even included in the associations distinguished mostly made

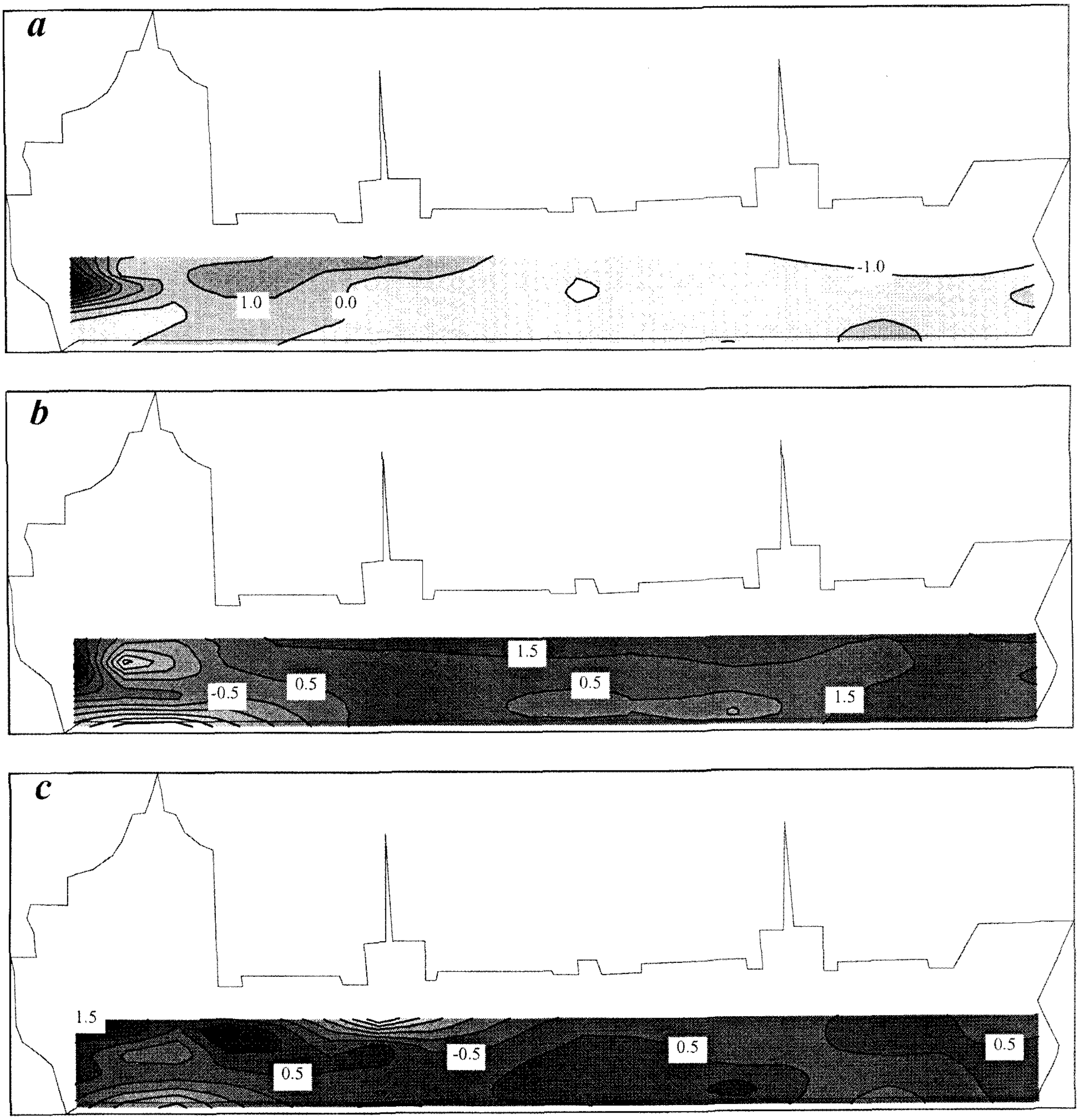

Fig. 4. Distribution of the factor values on the hull of the motor-ship "Pyatigorsk" (a, b, c are the 1st, the 2nd and the 3rd factors from the table 7, correspondingly)

up of less than 0.7.

4. Discussion

The fouling of the selected ships of six SRs in five cases was presented by different Cirripedia communities, and in one case of the community of the mussel *M. trossulus* was found. These mussels occurred in fouling layers of the ships of all SRs, excepting the Russia-Vietnam route, as a typical or secondary species. The *B. crenatus* community observed on the ships of the Bering Sea SR was an intermediate succession phase. During a similar period, the climax community of the mussels using these barnacles as a substratum was known to be formed on the coastal ships in the Peter the Great Bay (Zvyagintsev 1984).

The Classical succession process is characteristic for fouling communities. During the succession, specific populations of organisms replace others regularly, periodically and inversely (Redfield and Ketchum 1952). At the same time on the transport fleet ships, the "inhibited" succession is quite frequent. This succession stops at a definite phase, for example, at the stage of barnacle community.

Gradients of abiotic factors render the essential influence on the formation pattern of the ship fouling community. So-called "physically controlled" communities consisting of eurytopic organisms are developed in this case. Such communities are typical for littoral and estuaries, formed during only in 1-3 years and rather easily reverted to a reset state after stressful effects (Oshurkov 1994).

Clear positive correlations between biomass of separate species and total biomass testified that the abundance of species entered in the community was far from their most possible magnitude, and basically determined by a certain general stress limiting factor (Sukhanov 1988; 1994). It was absolutely clear, that such factor was direct anthropogenic interference, i.e. the elimination of fouling during periodical clearning of ship hulls before these communities reached a climax stage. After both dry-docking and underwater clearing, the succession processes showed a similar pattern with those of the physically-controlled littoral or upper sublittoral communities, according to the ship draught.

The organisms forming climax communities, mussels and barnacles, were also found in the fouling layers of the selected ships. These fouling organisms were characterized by their high competitive ability, relatively long biotic cycle, large individual size, and high abundance. The fouling community alteration depending on a ship operation period, i.e. the anthropogenous succession, was subjected to the definite regularity and showed a quite predictable pattern.

The formation of the mussel community in the fouling of the ships operated during single navigation pew of may show some variations depending on the path and regime of ships floating. In the fouling of the investigated ships, different succession stages may occur even on the same vessel. Apparently, these deviations from the usual succession pathway with related to the fouling communities (or "types") of intermediate composition, i.e., when the community terminates the development at any intermediate stage (Zevina 1972; Rudyakova 1981). These deviations may explain the low level of the correlative relationships between the fouling biomass and duration of the ship operation period.

According to the Oshurkov (1993), so-called "fouling types", barnacle, hydroid, mussels, and so on, are only the different phases of the epibenthic succession, having some qualitative and quantitative traits. In conditions of sharp gradients of the hydrological and hydrodynamic factors (salinity in estuaries, turbulence in narrowities, around ship hulls and in tubings), this succession usually does not reach a climax and is finished at the formation level of relatively stable barnacle or bivalve community. Discrepancy in the formation stage and epibenthos structure on the anthropogenic and natural substrata is an artifact stipulated by the coincidence of the heterochronic associations of benthic organisms (Oshurkov 1993).

On the ships of the three Russia - Japan SRs, there was no mass elimination of cold-water species, in particular, *M. trossulus*. In the fouling or the most short route, the Russia - WestJapan SR, the succession of fouling communities passed similarly to that of coastal ships operating in the Peter the Great Bay where the mussel climax community appeared during one navigation (Zvyagintsev 1984). At the same time, some tropical and subtropical species of barnacles were included into a set of subdominant species of this community. These barnacles may also be a substratum for the mussel settlement. However, these barnacles occured in small amounts. It is possible, in mussels, there was a specific selectivity for the barnacle-substratum. This phenomenon may explain a weak contingency of the mussels and tropical barnacles. Mussels directly attaching to the ship hull without barnacle bed was weak and usually on the long-range voyage ships, the mussel community was not formed. Such situation may be observed on the ships lowered in water after repair at the end of the period of barnacles settlement.

A number of fouling species was known to drop with the increasing ship floating speed (Rudyakova 1981). In this case, the most eurytopic and strongly attached species, often the barnacles and goose-neck barnacles, usually survive in the fouling process. Less tolerant species were eliminated either because they cannot attach strong enough and withstand the water movement, or because they cannot obtain sufficient food in such conditions.

Naturally, we can reveal the connection between different parameters which describe fouling communities and the ship travelling speed if we use enough representative data sets including the data on ships with different travelling speeds. The clear display of these connections is expected only in the long SRs, when the ships continuously sail in the open sea for a long time. A significant negative correlation between total animal and algal biomass, and speed for the ships of the Bering Sea and Russia - Vietnam SRs, is a clear example of this suggestion. The Russia - Cuba route was represented here only by 3 ships of one type, and other SRs were either much shorter or insufficiently representated data sets.

The fouling formation on the ships of the Russia-Vietnam SR had following stages: First, development of the oceanic fouling during the transition from the East Sea to Vietnam; Second, elimination of the "cold-water" fouling during the anchorage in tropics and also in riverine ports of Chaiphong and Choshimin; and third, fast formation of either coastal or oceanic fouling in the following voyage. The development of last two fouling types usually depends on the duration of anchorage after a ship departs from the river. Consequently, on the ships of the Russia - Vietnam SR, the fouling is represented by oceanic, and also by coastal tropical and subtropical species, and, there was no *M. trossulus* community on these ships.

On the hull of the Pyatigorsk, three animal associations, those of barnacles, bryozoans and mussels, were found, however they were not clearly scattered in the hull space. Whereas, only one practically monodominant community of the mussels *M. trossulus* was distinguished in terms of average biomass. Similar phenomenon was observed on the experimental plates exposed in Amursky Bay, in absolutely similar hydrological conditions (Zvyagintsev *et al.* 1990). During one navigation on some plates, the community of the mussels using the *B. crenatus* bed as a substratum was formed. On others, the succession was interrupted at the stage of the *B. crenatus* community without the mussels, and on another plates,only the encrusting bryozoans were found. Apparently, at early stages of succession in the formation of fouling communities, there were some latent mechanisms, which should be clarified by future experiment.

It is interesting that spatially scattered associations of the organisms of different geographical origin may coexist on the hull of the same ship. On the hull of the Galich the association *B. crenatus*+*M. trossulus*+*C. intestinalis* was the most abundant in the stern part and displayed a typical moderate boreal species complex. The subtropical-tropical complex of the another association, *B. amphitrite,* was located to the midsection and bow parts of the ship. Therefore, it should be emphasized that the delimitation of fouling communities according to the species average biomass accounted for a whole hull was not absolutely correct. If, for example, we examine only the stern part of the Galich, then the *B. crenatus* community that is not typical for the Russia-South Japan SR, but is so for the Bering Sea SR will be revealed.

The formation of spatially scattered complexes on the hull of the same ship, undoubtedly, is connected with the divergence of the dominant species into their proper ecological niches. The settlement of accompanying organisms would be a result of the actions of dominant species on a habitual substratum. The factor playing the main part in the dominant species divergence is a subject of a special investigation, because the literatures on the temperature adaptations and temperature differences between some parts of a ship hull, which may be the result of the heating due to the mechanical action, are not yet clean on such subject.

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