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Article

# Distributional Characteristics of Macrofouling Organisms on Ocean-going Ships of the Far East Sea Basin

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**Abstract :** Distribution features of foulers attached on 28 ships of 6 main shipping routes (SR) of the Far East Sea Basin were analyzed using various statistical methods. Collections obtained during 1976-1990 in the expeditions by the Institute of Marine Biology were used for the analyses. Samples were taken from the ships during anchorage by SCUBA diving and from dry-docks of Vladivostok ship-repairing yard. In all cases, the distribution patterns of most animals and algal species showed clear contagious patterns. Total biomass of fouling organisms and biomass of attached animals frequently increased along the horizontal direction of ship hulls, from the stem to the sternpost. Animal and algal species were usually located at different sites of the hulls. According to the increasing floating speed, there was, a clear tendency of the displacement in main fouling biomass from the stem to the stern. Any generalizations and deductions concerning the distribution patterns of the foulers from the same SR ships are not always substantiated, but one may see some similarities of the fouler distributions in many cases. Micro-scale turbulence generated by water flow around a ship hull for the distribution of fouling organisms is discussed.

**Key words :** fouling organisms, ship, shipping route, distribution, algae, animal, barnacles, biomass, micro-scale turbulence.

## 1. Introduction

Many fouling specialists have been studying the distribution of foulers on hulls of the ocean-going ships. Horizontal, *i.e.* from the stem to the sternpost, fouling distribution on the coasting ships usually sailing under low speed (up to 8-10 knots), was found to be rather uniform. For higher-speed ships, some information on the distribution of fouling along the hulls as well as hydrodynamics in the variability of fouling patterns are already well reported in literature (Igic 1968; Zvyagintsev and Mikhailov 1978; Mikhailov 1985a,b; Mikhailov and Blinov 1981; Revin 1981). And the studies showed that the ship floating speed was shown to be one of the main factors controlling composition, structure and distribution pattern of fouling communities.

In this sense, a number of Rudyakova (1958; 1967a,b; 1981) papers are of the most interest. She carefully analyzed some features of settlement and distribution of main foulers (barnacles, mussels, hydroids) on the ships sailing in the Far East Sea Basin. Although her works are only descriptive, and the deductions have been made "only logically ... without adducing concrete numerical characteristics" (cited after Rudyakova 1967a), these observations are very important. For example, the author notes some increases of the settlement density and shell sizes of barnacles along the ship hulls, from the bow to the stern. These variations, she explains, are not by a sequence and heterochronity of the appearance of barnacle larvae around the ship, but are connected with a flow pattern around ship hulls. Barnacle cyprids are known to possess a specific behavioral trait. They do not attach even to the suitable substrata without some minimal level of water movement that is a necessary requirement of their further survival (Crisp 1955). Rudyakova (1981) admits that turbulent water flows are exactly the reason for the settlement pattern of barnacle larvae. Generally, this concerns the littoral species *Semibalanus cariosus* and

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*Balanus balanoides*, but some data show that sublittoral species *Balanus crenatus* also forms gregarious aggregations in the stern part of fishing vessels (Mikhailov 1985b).

Rudyakova (1981) also noted inconsistency of the data obtained by different authors studying the fouling distribution and the relations of foulers during settlement, and concluded that this problem is very complicated and should be specially investigated. According to her papers, in barnacles, there is only a tendency to occupy all free hard substrata more or less uniformly.

This work is continuation of our previous paper devoted to the composition and structure of the fouling communities inhabiting the ocean-going ships of the Far East Sea Basin (Moshchenko and Zvyagintsev, in press). In it, we showed that for ships of the same SR(Ship Route), the fouling communities possess similar composition. In five cases, the fouling community was mostly represented by different Cirripedia communities, and in one case, a community composed of the mussel *Mytilus trossulus* was observed. The results of factor analyses showed an extremely low level of the relationships between different animal and algal species in most cases. Each ocean-going ship had original structures of fouling. Also, spatially disconnected animal associations of tropical or boreal origin may simultaneously coexist at the same ship.

The goal of this work was to study the distribution of main fouling organisms on the hulls of the ships travelling in the Far East Sea Basin.

## 2. Materials and methods

The samples were collected during the expeditions carried out by the Institute of Marine Biology of Far East Branch of Russian Academy of Sciences in 1976-1990. Most of the samples were taken from ships during anchorage by SCUBA according to the methods and scheme worked out by Zvyagintsev and Mikhailov

**Table 1. Some characteristics of the ships.**

| Ship name | Shipping route | Duration of operation period, months | Floating speed in ballast, knots | Presence of bow bulb |
|---|---|---|---|---|
| Ivan Babushkin | B | 8 | 14.0 | – |
| Byelorussia | B | 10 | 11.5 | – |
| Chukotka | B | 10 | 14.0 | – |
| Kozyrevsk | B | 9 | 14.6 | – |
| Rzhev | B | 15 | 16.9 | + |
| Yakov Sverdlov | B | 9 | 14.0 | – |
| Mikhail Uritskii | B | 14 | 18.2 | – |
| Dalny | REJ | 6 | 14.1 | – |
| Galich | REJ | 6 | 12.0 | – |
| Undzha | REJ | 6 | 15.0 | – |
| Petropavlovsk-Kam. | RSJ | 10 | 11.5 | – |
| Primorles | RSJ | 6 | 16.0 | – |
| Suhona | RSJ | 7 | 12.4 | – |
| Ulyanovsk | RSJ | 10 | 11.5 | – |
| Andoma | RC | 6 | 16.0 | – |
| Pripyat | RC | 6 | 16.0 | – |
| Vorkuta | RC | 3 | 16.0 | – |
| Dalny | RV | 7 | 14.1 | – |
| Ohaneft | RV | 7 | 16.4 | – |
| Larisa Reisner | RV | 5 | 19.3 | + |
| Nikolai Semashko | RV | 5 | 17.2 | + |
| Svirsk | RV | 8 | 14.0 | – |
| Volgograd | RV | unknown | 18.5 | – |
| Donbass | RWJ | 8 | 11.5 | – |
| Pioner Rossii | RWJ | 8 | 16.5 | – |
| Bikin | RWJ | 8 | 14.1 | – |
| Pyatigorsk | RWJ | 8 | 16.9 | + |
| Aleksei Chirikov | RWJ | 8 | 11.5 | – |

Shipping routes: B - Bering Sea, REJ - Russia - East Japan, RSJ - Russia - South Japan, RWJ - Russia - West Japan, RC - Russia - Cuba, RV - Russia - Vietnam.

(1980). Some other ships were also examined in dry-docks by similar scheme. In total, 28 ships were investigated and 28 qualitative and 426 quantitative samples were taken and treated. Flora and fauna collected from the ship hulls were identified to species level, weighed up to 0.001 g accuracy (raw mass), and settlement density was determined for solitary animals.

Because of a wide variety of ship operation modes (the running regime, alternation frequency between float and anchorage, duration and timing of navigation, extent of the route, etc.), and variety of constructions and protective coatings of the hulls, it is rather difficult to receive adequate data on the organism distribution. 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 of the examinations of 28 ships of the 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), Russia-Cuba route (3). Some characteristics of the ships studied are shown in Table 1.

To analyze the distribution of fouling organisms, we chose the ships from which the greatest number of samples were taken (not less than 10 samples from a ship). The abundance of fouling species was estimated using frequency (P), biomass (B), settlement densities (A, for solitary animals), and derivative index $\sqrt{P \times B}$. To evaluate the distribution pattern of solitary animals, a dispersion index was used (Elliott 1971; Maximovitch and Pogrebov 1986): $I_w = \sigma^2 / \bar{X}$, where $\sigma^2$ is variance and $\bar{X}$ is the mean settlement density. In random distribution, $I_w = 1$; $I_w > 1$ indicates a tendency toward aggregation, and $I_w < 1$ points out on a regular distribution. The significance of the differences of $I_w$ from 1 was examined by a statistical formula $d = \sqrt{2\chi^2} + \sqrt{2v - 1}$, where $\chi^2$ is goodness-of-fit criterion, and $v$ is the number of degree of freedom. To derive a parameter describing the distribution of fouler biomass, the coefficient similar with the dispersion index was counted: $I_{wb} = \sigma^2 / \bar{X}$, where $\bar{X}$ is the mean biomass of algae and animals. In addition, to

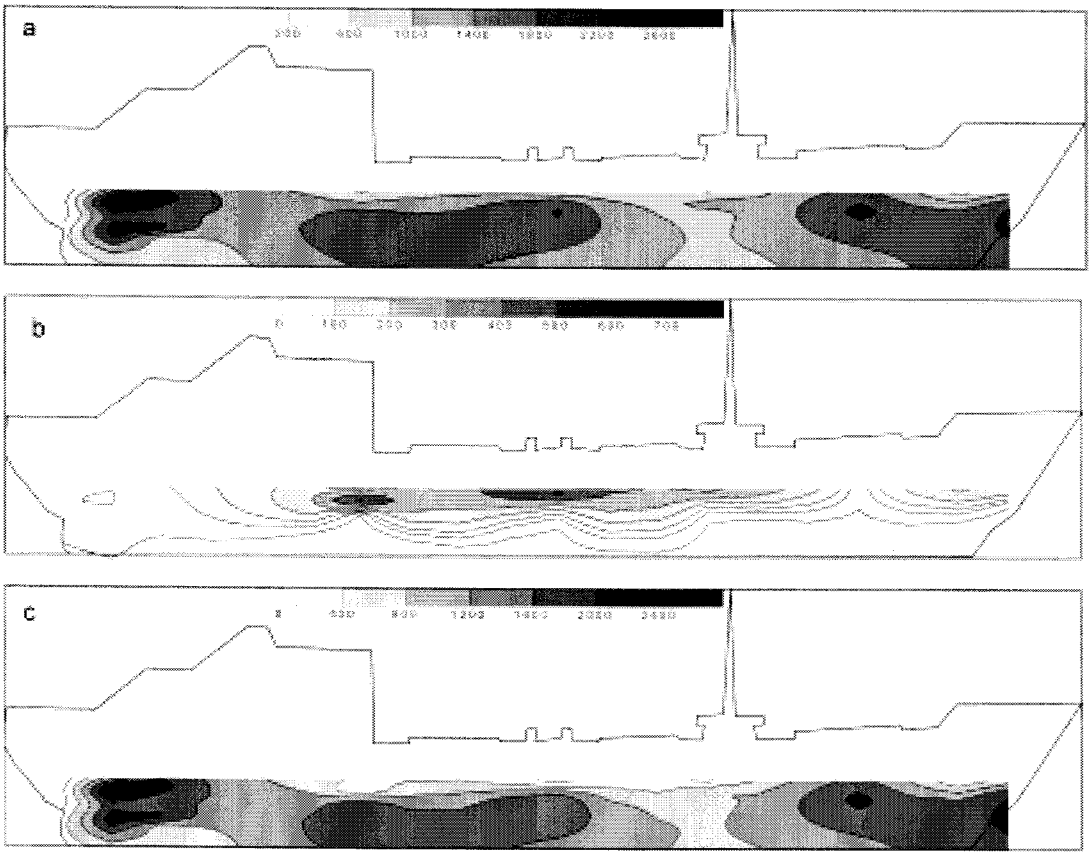

**Fig. 1. Distribution of total biomass (a), algae (b) and animal (c) biomass on the hull of the motor-ship "Galich", Russia-East Japan SR. Scale bar-g/m$^2$.**

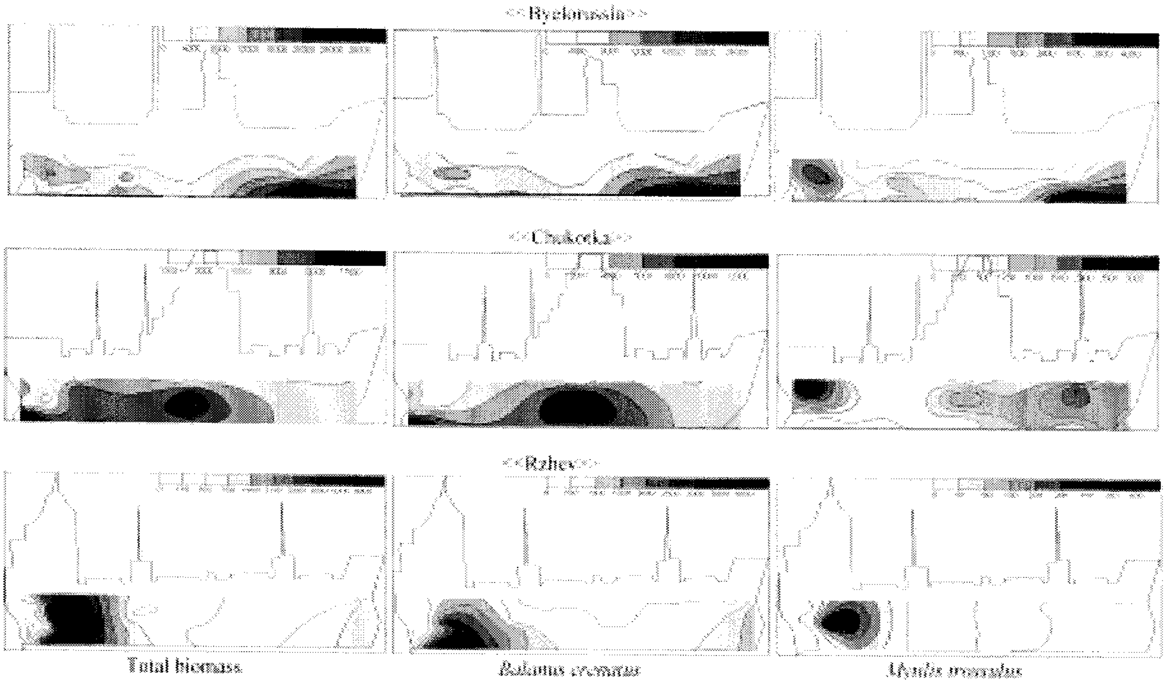

**Fig. 2. Distribution of total biomass and biomass of dominant and subdominant species on the hulls of the ships of the Bering Sea SR. Scale bar-g/m$^2$. Here and at figs. 5 and 7, horizontal/vertical ratio for ship hulls is 1/2.**

estimate tendencies in the fouler distribution along the vertical (from the waterline to the ship bottom) and horizontal (along the ship hull) directions, the correlation coefficients between total biomass, algal and animal biomass, and standard for all ships relative vertical and horizontal coordinates were computed ($R_y$ and $R_x$, correspondingly). For horizontal coordinates, a zero point was established at the outermost sternpost (at the chine line for vertical coordinates), and 1 point was placed at the outermost bow (at the waterline for vertical coordinates). Hence, relative horizontal and vertical coordinates were computed as $l/L$ and $h/H$, correspondingly, where $l$ is the distance from the horizontal zero point, $L$ is the ship length, $h$ is the distance from the vertical zero point, and $H$ is the distance from chine line to the waterline.

## 3. Results and discussion

The distribution of total biomass, biomass of algae and most of animal species showed a clear pattern at all ships studied. First of all, the distribution pattern was concerned with dominant, subdominant and mass species (Figs. 1, 2). Algae (for example, *Ulva fenestrata, Enteromorpha linza, Ectocarpus confervoides*) were usually concentrated in upper part of ship hulls near the waterline, while animals were mosaically disposed on hulls' other parts. The distribution pattern of most frequently attached solitary animals was significantly wide, whereas that of motile forms usually did not contradict the random pattern. Frequently, total biomass of foulers and biomass of animals, which constituted from 55 up to 100 % of total biomass, increased significantly along horizontal direction from the stem to the sternpost (Table 2). In algae, this tendency was observed much less often. Instead, algal biomass frequently rose up from the ship bottom to the waterline.

Another common feature was a increasing tendency of biomass aggregation degree ($I_{wb}$ index) under the extension of ships' operation period (Fig. 3a-f). Also, a similar tendency was found in settlement density of some attached solitary animals, mainly barnacles ($I_w$ index, Fig. 3g,h). At Russian - Vietnam SR, high and significant decreases of dispersion indices with increasing ship floating speed were found for total biomass, total biomass of animals, biomass of attached animals, and settlement density of some attached solitary animals (Fig. 4).

Various animal and algal species were rather distinctly located at different parts of the hulls; that was well illustrated by the distribution of *U. fenestrata, E. linza* and several barnacle species at the motor-ship "Galich", one

Table 2. Some characteristics of the fouling communities on the ships.

| Ship name | $N_{SA}$ | $N_{SP}$ | $B_T$±SD | $B_{AG}$±SD | $B_{AN}$±SD | $I_{WT}$ | $I_{WAG}$ | $I_{WAN}$ | $R_{XT}$ | $R_{XAG}$ | $R_{XAN}$ | $R_{YT}$ | $R_{YAG}$ | $R_{YAN}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ivan Babushkin | 25 | 6 | 2341.6±1487.0 | 871.5±1214.9 | 1470.2±1307.0 | 944.3 | 1693.8 | 1161.9 | –.422 | –.097 | –.390 | .302 | **.585** | –.200 |
| Byelorussia | 25 | 22 | 8028.8±7223.3 | 31.7±63.1 | 7997.1±7237.7 | 6498.7 | 125.5 | 6550.4 | .377 | .019 | .376 | –.348 | .175 | –.349 |
| Chukotka | 23 | 25 | 6399.8±5040.3 | 176.5±457.6 | 6046.8±5190.6 | 3969.6 | 1186.4 | 4455.6 | –.299 | –.209 | –.254 | –.354 | .062 | –.355 |
| Kozyrevsk | 14 | 14 | 3178.9±4584.6 | 357.4±506.4 | 2821.6±4458.6 | 6611.8 | 717.6 | 7045.3 | **–.638** | –.156 | **–.638** | –.182 | **.459** | –.239 |
| Rzhev | 24 | 19 | 1012.3±1580.5 | 78.6±154.2 | 933.7±1617.8 | 2467.6 | 302.7 | 2803.3 | –.365 | .114 | –.368 | –.059 | **.406** | –.097 |
| Yakov Sverdlov | 17 | 12 | 1100.8±828.0 | 495.3±553.9 | 605.5±946.9 | 622.9 | 619.5 | 1480.9 | **–.455** | –.019 | –.386 | –.129 | **.672** | **–.506** |
| Mikhail Uritskii | 7 | 8 | 2339.3±4341.4 | 64.2±165.7 | 2275.1±4373.0 | 8057.0 | 427.5 | 8405.5 | **–.843** | .407 | **–.852** | .114 | **.880** | .079 |
| Dalny | 6 | 11 | 1251.9±392.8 | 263.1±464.2 | 988.8±624.0 | 123.2 | 818.8 | 393.9 | **–.517** | –.363 | –.055 | –.041 | **.676** | –.529 |
| Galich | 29 | 31 | 1516.1±880.9 | 140.9±358.5 | 1375.2±986.6 | 511.9 | 912.2 | 707.8 | –.143 | .140 | –.178 | .024 | .326 | –.097 |
| Undzha | 6 | 16 | 1477.1±893.3 | 264.7±206.9 | 1212.3±824.0 | 540.2 | 161.7 | 560.0 | –.459 | –.764 | –.306 | –.031 | **.806** | –.236 |
| Petropavlovsk-Kam. | 12 | 12 | 374.8±473.6 | 111.3±171.5 | 263.5±446.8 | 598.4 | 264.2 | 757.6 | –.427 | –.219 | –.368 | **.609** | **.664** | .390 |
| Primorles | 9 | 6 | 220.4±138.3 | 44.7±86.1 | 175.7±127.0 | 86.8 | 165.8 | 91.8 | –.491 | .158 | **–.642** | –.185 | **.592** | **–.603** |
| Suhona | 6 | 10 | 1439.1±750.8 | 8.7±21.2 | 1430.4±760.4 | 391.7 | 52.0 | 404.3 | –.317 | .416 | –.324 | –.465 | **.783** | –.481 |
| Ulyanovsk | 9 | 11 | 1091.1±2138.1 | 18.4±31.7 | 1072.6±2128.4 | 4189.8 | 54.5 | 4223.4 | –.427 | –.679 | –.419 | .498 | .443 | .494 |
| Andoma | 24 | 14 | 1737.6±2518.1 | 79.4±234.3 | 1658.2±2552.8 | 3649.4 | 691.9 | 3930.0 | **–.478** | .170 | **–.488** | **–.491** | .142 | **–.498** |
| Pripyat | 18 | 9 | 1142.9±965.3 | 34.8±147.8 | 1108.0±995.8 | 815.3 | 627.0 | 894.9 | –.187 | .060 | –.190 | –.040 | .018 | –.041 |
| Vorkuta | 18 | 8 | 177.5±282.3 | 7.1±29.9 | 170.3±284.7 | 449.2 | 125.9 | 475.9 | –.032 | –.029 | –.028 | –.186 | .055 | –.191 |
| Dalny | 22 | 6 | 2539.2±1456.3 | – | 2539.2±1456.3 | 835.3 | – | 835.3 | **–.490** | – | **–.490** | –.056 | – | –.056 |
| Ohaneft | 12 | 9 | 643.3±619.1 | 18.5±60.7 | 624.8±623.7 | 595.8 | 199.0 | 622.7 | .074 | .120 | .062 | .118 | **.527** | .066 |
| Larisa Reisner | 10 | 6 | 491.2±480.0 | 6.9±10.0 | 484.3±479.1 | 469.0 | 14.6 | 473.9 | –.156 | .078 | –.158 | –.170 | –.278 | –.164 |
| Nikolai Semashko | 24 | 7 | 781.7±498.0 | 3.4±14.7 | 778.3±500.7 | 317.2 | 63.5 | 322.1 | –.239 | .266 | –.245 | **.515** | .121 | **.509** |
| Svirsk | 6 | 7 | 424.1±572.4 | – | 424.1±572.4 | 772.7 | – | 772.7 | –.578 | – | **–.578** | –.120 | – | –.120 |
| Volgograd | 12 | 10 | 422.0±232.5 | – | 422.0±232.5 | 128.1 | – | 128.1 | –.034 |  | –.034 | .004 | – | .004 |
| Donbass | 12 | 32 | 2051.0±1939.5 | 8.6±18.9 | 2042.4±1948.3 | 1834.1 | 41.3 | 1858.5 | –.429 | .372 | –.431 | –.116 | **.592** | –.122 |
| Pioner Rossii | 7 | 15 | 3879.7±5735.7 | – | 3879.7±5735.7 | 8479.5 | – | 8474.1 | **–.743** | – | **–.743** | **.705** | – | .705 |
| Bikin | 7 | 19 | 1820.7±1041.2 | 401.1±632.8 | 1419.6±1153.0 | 595.4 | 998.4 | 936.5 | **–.932** | –.002 | **–.841** | –.426 | .536 | **–.679** |
| Pyatigorsk | 44 | 42 | 1552.8±2485.8 | 27.3±63.5 | 1525.5±2478.1 | 3979.2 | 147.6 | 4025.5 | –.224 | .004 | –.225 | .128 | .395 | .118 |
| Aleksei Chirikov | 20 | 20 | 2952.7±4298.7 | 53.5±146.2 | 2899.1±4332.1 | 6258.4 | 399.6 | 6473.2 | **–.511** | .110 | **–.511** | .156 | –.010 | .155 |

N - number: SA - samples, SP - species, B - averaged biomass, g/m$^2$; SD - standard deviation, $I_W$ - dispersion index for biomass; $R_X$ and $R_Y$ - correlation coefficients between biomass, and horizontal and vertical coordinates, correspondingly; T - total, AG -algae, AN animals; significant ($p<0.05$) R are boldfaced; dash shows that algae were not found.

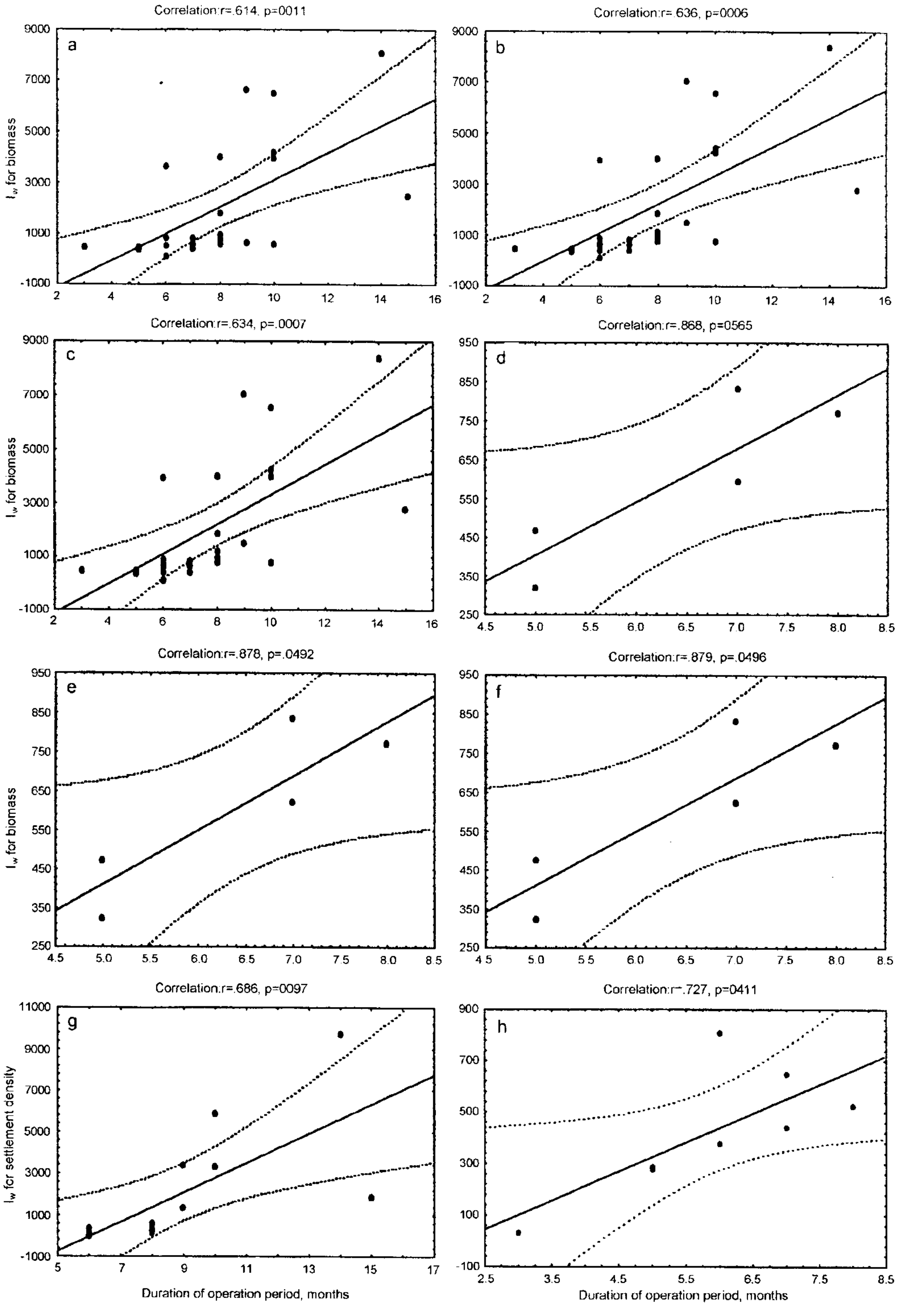

Fig. 3. Correlation between duration of ship operation period and dispersion indices for biomass (a-f) and settlement density (g, h): a-c - total biomass, animal biomass, and biomass of attached animals, correspondingly, for all ships studied, excluding "Pioner Rossii" and "Aleksei Chirikov"; d-f - the same items for Russia - Vietnam SR; g, h - density of *Balanus crenatus* and *Balanus reticulatus*, correspondingly, for ships of different SR. Here and at figs. 4 and 6 solid lines are regressions; dotted lines show confidence limits.

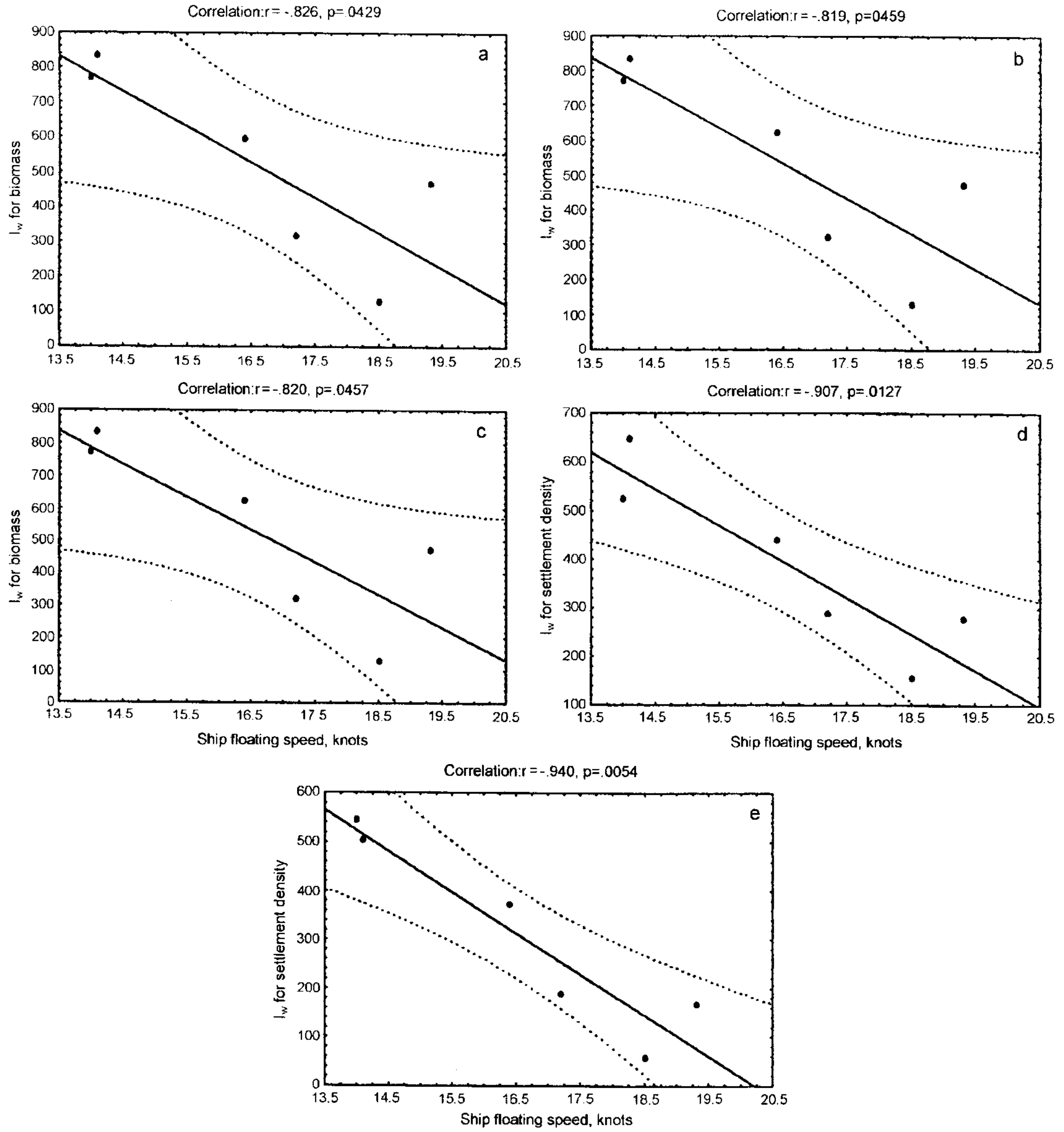

**Fig. 4. Correlation between ship floating speed and dispersion indices for biomass (a-c) and settlement density (d, e) for Russia - Vietnam SR: a-c - total biomass, animal biomass, and biomass of attached animals, correspondingly; d - for *Balanus reticulatus*, e - for *Balanus amphitritae*.**

of the most carefully studied ships with diverse and abundant fouling community. The highest biomass of *U. fenestrata*, as well as *E. linza*, was observed near the waterline, but it was situated closer to the stem, at the end of cylindrical insertion, whereas *E. linza* was more abundant at the beginning of cylindrical insertion and at its middle part (Fig. 5). The biomass of *Balanus albicostatus* was maximal at the below the waterline in the stem part of the hull, where as the main biomass of *Balanus improvisus* was located at the stem and bottom parts of the midsection, and that of *Balanus eburneus* was observed at the end of the cylindrical insertion and in the stern part, etc.

The distribution, composition and abundance of fouling organisms inhabiting ship hulls inevitably depend on the environmental conditions of the places of settlement, and, particularly, on the hydrodynamic characteristics of the ship boundary layer: the streamline flow velocity, the thickness of the viscous laminar sublayer, the degree of the flow turbulence, the distribution of the values of

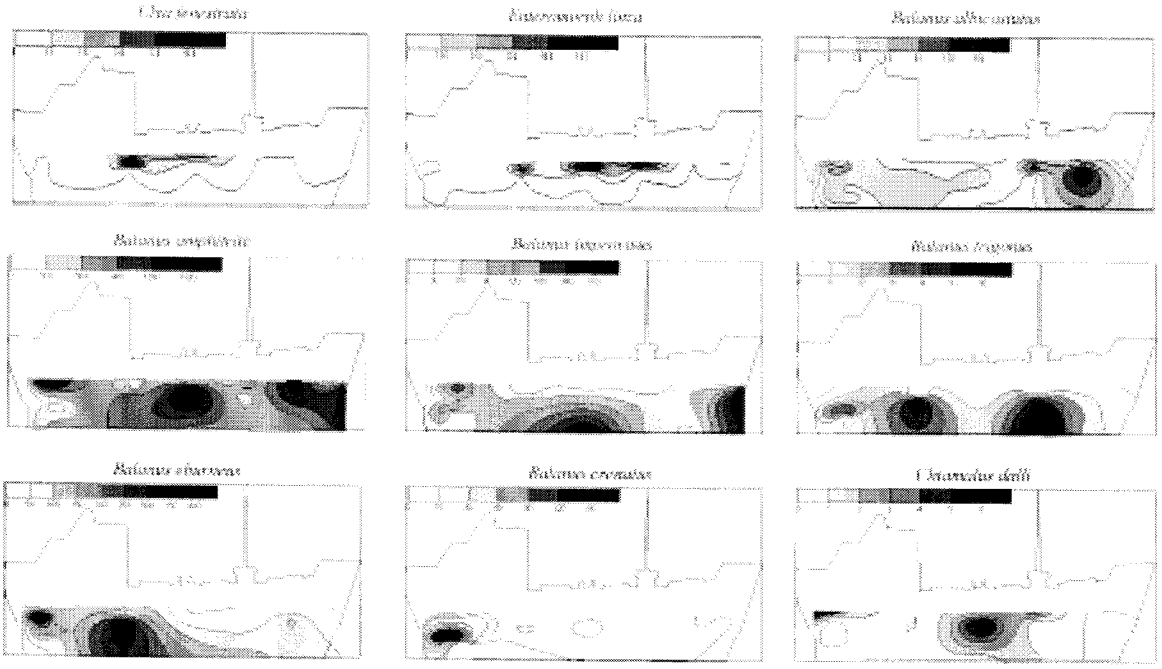

**Fig. 5. Distribution of the biomass of some fouling organisms at the hull of the motor-ship "Galich", Russia - East Japan SR. Scale bar-g/m$^2$.**

variable pressure gradient, etc. At the same time, rather different number of samples were frequently taken from ships, and the sampling scheme were rather different in some cases. In addition, ships are different among each

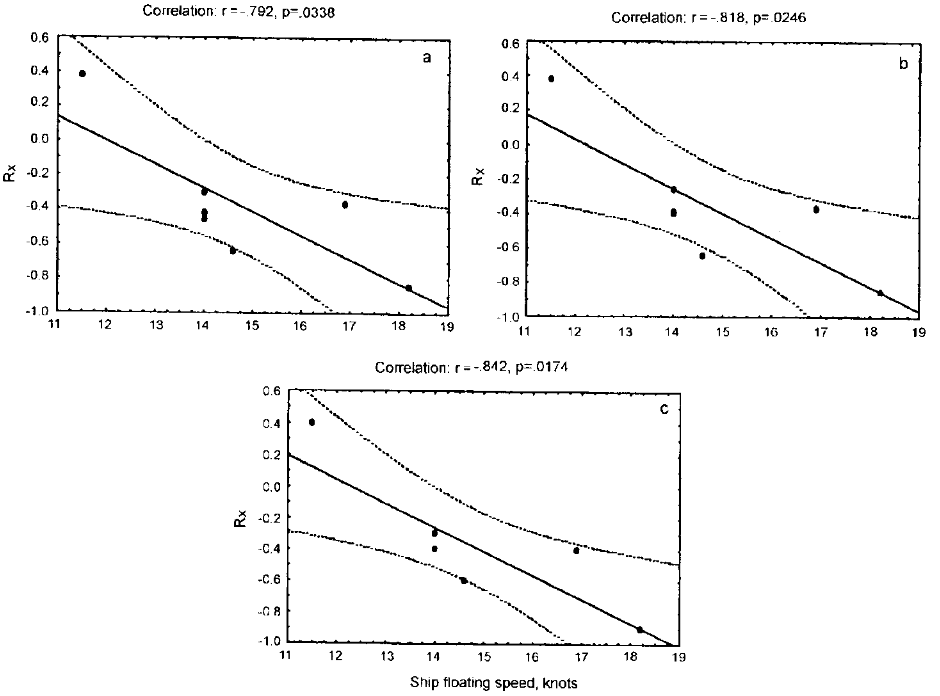

**Fig. 6. Correlation between ship floating speed and $R_X$-coefficients for the Berring Sea SR: a - total biomass, b - animal biomass, c - biomass of attached animals.**

other in duration and periods of operation, working region, etc. Thus, our samples were rather restricted and insufficient for strict statistical estimations in the significance of influence, for example, the ship floating speed on the distribution of fouling organisms, in many cases. Therefore, we did not find any significant correlation between $I_w$ and $I_{wb}$ indices and ship floating speed for the Berring Sea SR.

Despite of it, a clear tendency was found in the displacement of main fouling biomass from the stem to the stern under the increasing average ship floating speed. For example, on the motor-ship "Byelorussia" (floating speed in ballast is 11.5 knots and that in freight is 10.5 knots), the maximal fouling biomass was limited to the bow part of the hull; on the motor-ship "Chukotka" (14.0 and 13.0 knots, correspondingly), the maximal fouling biomass was located at the midsection and at the end of the cylindrical insertion, on the motor-ship "Rzhev" (16.9 and 16.1 knots), the maximal fouling biomass fell on the stern part of the hull (Fig. 2). As a whole, at the ships with the Bering Sea SR, the coefficients $R_X$ for the total biomass, total animal biomass, and biomass of attached animals were negatively correlated with floating speed (Fig. 6). Therefore, a tendency of the displacement maximal biomass from the stem to the stern became more clearer under the increasing floating speed. A similar tendency, although expressed differently, was found for the ships of other SRs. For example, for Russian-Vietnam SR, correlation coefficients for the same items ranged 0.699 – 0.733 albeit insignificant: $p = 0.0930 - 0.1220$. At the same time, the patterns of fouling distribution may extremely vary even for the ships of the same type, same SR, same duration and period of operation. In many cases, we found only some similarities of the distribution patterns. An illustration of this conclusion may be three timber ships of the "Volgales" type, the "Andoma", "Pripyat" and "Vorkuta", plied along the Russia-Cuba SR (Fig. 7).

The wide distribution of fouling organisms may be explained by three main reasons (Crisp 1955; 1974; Crisp and Meadows 1962; 1963; Meadows and Campbell 1972; Scheltema 1974; Eckman 1983) as follows.

- Intra-species attraction occurring when settled individuals secrete substances promoting the settlement of the same species larvae;
- Formation on ship hulls where some areas are different from other places in physical or chemical (protective coating differences in latter case) conditions

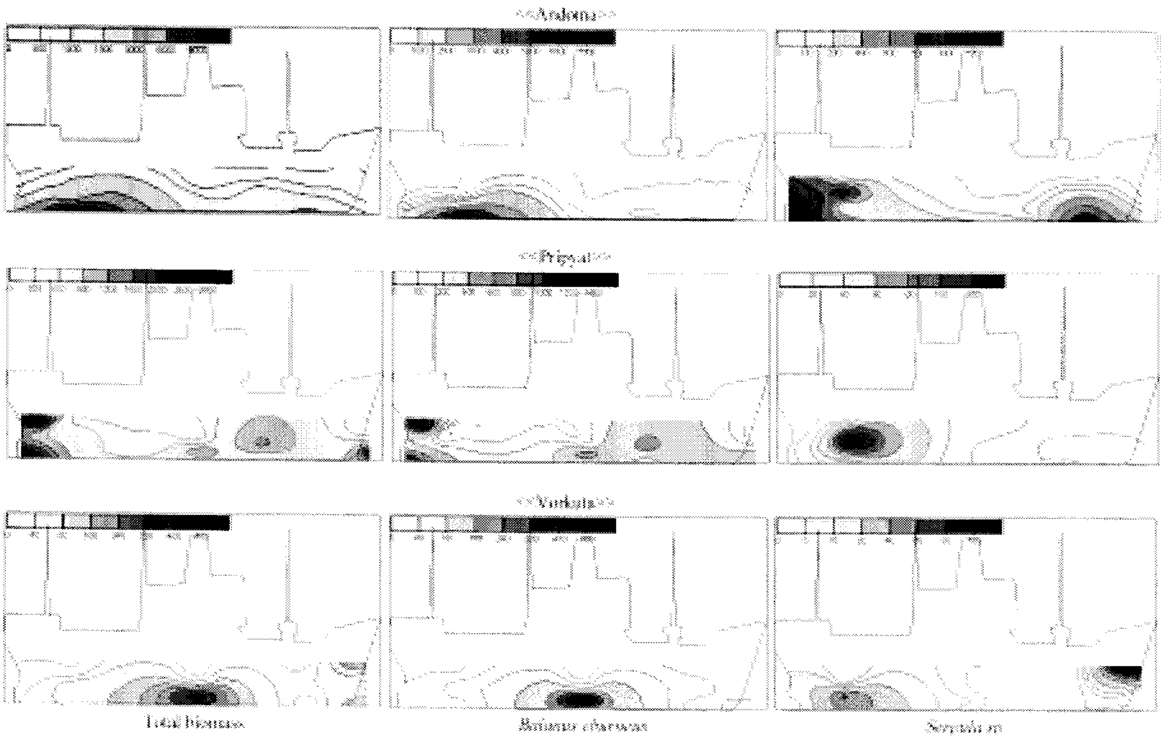

**Fig. 7. Distribution of total biomass and biomass of dominant and subdominant species at the hulls of the ships of Russia - Cuba SR. Scale bar - g/m$^2$.**

promoting or precluding the successful attachment, development and growth of organisms;

- Insufficiently represented quantitative data. In an ideal case, we should increase the number of samples collected from each ship by one or two orders, and use the regular sampling along 1 m not only along vertical, but also along horizontal directions. Unfortunately, these variants of sampling are practically unreal because of extreme increases in sample numbers.

The method of sample collection used in this work possesses rather numerous shoot-comings (Greig-Smith 1967; Pielou 1977, where different sampling methods have been discussed and compared). Here, we carefully consider the first two reasons only among three reasons mentioned in previous paragraph. Naturally, the degree of aggregation positively correlated with the duration of ship operation between docking which more or less confirms the significance of the intra-species attraction: the wide distribution was expressed more on the ships operating more than one year, *i.e.* on the ships exposed more than one period of larval settling. But this assumption does not show any explanation of the decrease in aggregation and the displacement of the main fouling biomass to the stern part of a ship with increasing floating speed which were observed on the ships of some SRs. The main reason probably is the heterogeneity of the hydrodynamics around ship hulls and, particularly, the differences of the micro-scale turbulence development. Lastly, the fouling community formation on the hull areas was noticeably different probably due to different pressure rendered by waters to ship hull (Fig. 8). In shear locations, *i.e.* in the zones of the appearance of micro-scale eddies, the pressure drops.

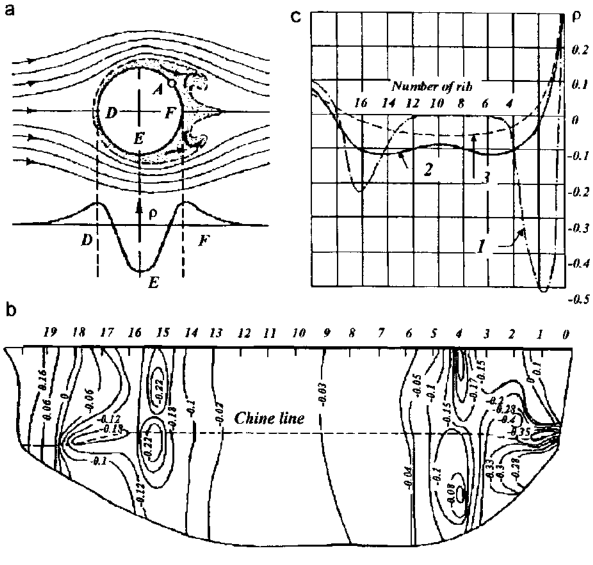

**Fig. 8. Scheme of boundary layer shear (A is point of shear), vortex development and pressure profile around a cylinder (a); pressure distribution over a model of tanker (b) and pressure profiles along horizontal axis of the hulls of different type ships (c: 1 - tanker, 2 - dry-cargo ship, 3 - high-speed ship); to characterize pressure variability, pressure coefficient was used; a - after Schlichting (1956); b, c - after Voitkunovskii (1985).**

In case of turbulent flow, the eddies regularly penetrate into the viscous sub-layer of the near bottom boundary layer (Grinvald and Nikora 1988). This regular penetration increases the probability of larvae approaching the substratum (Butman 1986). As a result, on natural and artificial substrata, many animals settle near shear localities, *i.e.* in the sites of heavy development of micro-scale turbulence (hereinafter: MST). Micro eddies promote not only the larvae approaching, but also the approaching of the objects that are included in rations of attached animals, many of which, for example, barnacles and hydroids, are active predators. In case of micro vortex water movement, the probability of prey capture is known to rise (Riedl and Forstner 1968 ; Chamberlain and Graus 1975; Leversee 1976; Muzik and Wainwright 1977; Rubenstein and Koehl 1977) due to the increase of the frequency of predator - prey encounters (Rothschild and Osborn 1988).

These facts allowed us to explain, although at a hypothetical level, many features of the fouling distribution observed on ship hulls. For this purpose, it was enough to compare the patterns of animal distribution (Figs. 1, 2, 5, and 7) and those of pressure magnitudes (Fig. 8b), taking into account the pressure variations observed at hulls of the ships of different type and floating speed (Fig. 8c). One may see the obvious matching of the areas of minimal pressure values, *i.e.* the zones of high MST development, and those of maximal biomass of animals. More uniform horizontal pressure distribution along the most part of the hulls of high-speed ships, *i.e.* the absence of clearly expressed areas of high MST development, may cause the decrease of the aggregation with increasing floating speed. Such phenomenon was detected, for example, at the ships of the Russia-Vietnam SR. The displacement of main fouler biomass from the bow to the stern with increasing floating speed may be a result of the displacement of the areas of high MST along this direction.

In the first approach, the next procedure was carried out to check these assumptions. The pressure values were read out from the fig. 8b. These magnitudes were compared with the total biomass of foulers. The results of this counting showed that the maximal biomass matched with the zones of low pressure values, *i.e.* the locations of shear areas. The correlation coefficient between biomass and pressure values for all ships studied averaged 0.748 ± 0.252 and varied, approximately, from 0.4 up to 0.9. Correspondingly, the determination coefficient may reach 80 %.

The highest correlation coefficients were found for relatively slow-speed and older ships, where as the lowest ones were observed in more modern and high-speed ships. The form of underwater part for the former ships was similar to that shown at figs. 1, 2 (two upper rows), 5, and 7. More modern and high-speed ships represented in our samples possess the bow bulb (Fig. 2, lower row). In the case of the bow bulb, the convergence of flow lines is known to be smoother than without the bulb, and the intensity of chine vortices drops (Voitkunovskii 1985). Hence, in this case, the pattern of the distribution of shear areas* (or zones of heavy MST development) would be rather different from that shown at fig. 8b. Unfortunately, to check these assumptions more carefully, the concrete hydrodynamical characteristics of each ship are necessary, in the future.

The proposed hypothesis allowed to explain somewhat a weak contingency of most fouler species that was revealed in the analyses of the relationships between animals and algae inhabiting ship hulls (Moshchenko and Zvyagintsev 2001). Many animals and algae are known to be strongly differentiated in relation to different environmental factors that causes the separation of their ecological niches. The hydrodynamical gradients around ship hulls are enough to cause selections of each fouling species for proper optimal area.

The assumption on species differentiation along the gradients of the intensity of MST allows us to make an intelligible explanation of the presence of two spatially disconnected animal associations on the hulls of the ship "Galich" (Moshchenko and Zvyagintsev 2001). The first association, *Balanus crenatus* + *Mytilus trossulus* + *Ciona intestinalis* mentioned on fig. 3a of the paper cited, was the most abundant in the stern part of this ship and represented a typical moderate boreal complex of species. Subtropical-tropical complex of the second association, *Balanus amphitrite* (Fig. 3b accompanying species are *B. eburneus* and *Nereis pelagica*), coexisted with the first one on the hull of the same ship, but it was located at the middle section and bow parts. Formation of these complexes may be a result of the divergence of dominant species into their "hydrodynamic niches", and the settlement of accompanying organisms may be a result of the action of first ones as a substratum for the later invaders (naturally, for *M. trossulus, C. intestinalis* in former case, and for *N. pelagica* in the latter one).

Another possible mechanism of MST action can be more intensive washing of toxicants from protective coatings from ship hulls (Revin 1981). Such a hypothesis also may be real for ships, but it does not match with natural phenomena, *i.e.* with settlement of animals near the shear localities at natural substrata.

The settlement of green algae at lighted parts of ship hulls, near the waterline, corresponded to the classical ideas on their existence only in euphotic zone. The narrowness of the green algae band on ship hulls is explained in terms of light dispersion and absorption by turbulent water flow off the waterline (Redfield and Ketchum 1952). At the same time, different illumination is hardly a reason for the animal settlement at different parts of ship hulls. For example, the barnacles are known to settle on the lighted vertical boards of ships from the waterline up to the keel, and on the shadowed bottom with similar success (Redfield and Ketchum 1952). The mussels are able to survive in complete darkness, for example, inside tubings, where they reach enormous biomass (Redfield and Ketchum 1952). Low similarity of the fouling distribution patterns even on the ships of the same type, same navigation period and duration, apparently showed the necessity of the measurement of much more wide sets of natural and anthropogenic factors (Railkin 1998) in the future for this complicated phenomenon.

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*To speak more correctly, the development and position of MST zones over a ship hull is influenced not only by the shear phenomenon (*i.e.* the appearance of MST zones due to friction only) but also due to the form of the ship, hull and wave action (Pavlenko 1956). At figs. 8b and c, all the components were taken into account. More detail discussion of these components and their influence on MST development is out of the our work for now.

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