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MACROZOOBENTHOS OF THE SUSUYA RIVER ESTUARY (SAKHALIN ISLAND): I. HYDROLOGICAL CHARACTERISTICS OF THE ESTUARY, SPECIES COMPOSITION AND DISTRIBUTION OF MACROZOOBENTHOS

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The paper provides description of species composition of macrozoobenthos, its structure, quantitative indicators, and features of distribution along the riverbed of the Susuya River estuary (Sakhalin Island). By hydrological characteristics and macrobenthos parameters, the main biotopic zones of the estuary are distinguished: the mouth (polyhaline zone), the lower estuary polyhaline–mesohaline zone, the middle estuary oligohaline zone, the upper estuary δ-chorohaline zone, and the freshwater zone. In total, 58 species of bottom hydrobionts were found in the river estuary. Malacostraca, 22 species, forms the basis of the species composition. Amphibiotic insects account for 15 species; Polychaeta, 9 species; and Mollusca, 7 species. Other groups are represented by 1–2 species. Each identified zone features its own, specific composition of bottom hydrobionts. Species richness decreases from the mouth with the sea salinity of water (30 species) to the α-chorohaline boundary (12 species) which corresponds to provisions of the theory of critical salinity. The value increases to 20 species when moving to the freshwater zone of the riverbed. The density of macrobenthos rises from (476 ± 59) ind.·m^{-2} at the river mouth to (6,653 ± 915) ind.·m^{-2} in the center of the lower estuary. The minimum density, (653 ± 72) ind.·m^{-2}, characterizes the α-chorohalinicum, while the maximum one, (3,529 ± 336) ind.·m^{-2}, is confined to the upper estuary. The basis of macrozoobenthos density is formed by polychaetes, gastropods, and amphipods in the lower estuary; by polychaetes, amphipods, and oligochaetes in the middle estuary; and by oligochaetes and dipterans in the upper estuary. Four areas with high biomass were registered: the lower estuary, (51.2 ± 5.7) g·m^{-2}; the middle estuary, (190.5 ± 41.2) g·m^{-2}; the upper estuary, (397.5 ± 82.0) g·m^{-2}; and the riffle separating the estuary from the freshwater zone of the riverbed, (23.4 ± 2.78) g·m^{-2}. At the river mouth, decapods form the basis of macrozoobenthos biomass. Upstream, the main contributors are bivalves, chiefly *Macoma balthica*, and gastropods, mostly *Fluviocingula nipponica*. In the middle estuary oligohaline zone, bivalves form the basis of macrozoobenthos biomass; those are represented almost by *Corbicula japonica* alone. At the boundary of the oligohaline zone and upper estuary, Diptera species (Chironomidae) predominate. On the freshwater riffle, decapods become the main group again; those are represented by a crab *Eriocheir japonica* alone. The boundaries between the mouth and lower estuary zone, α-chorohalinicum and δ-chorohalinicum, are clearly distinguished by macrobenthos abundance and structural indices. The boundary between the upper estuary oligohaline zone and freshwater zone extends for several hundred meters along the estuary.

Keywords: estuary, salinity, macrozoobenthos, density, biomass, Sakhalin Island

An estuary is a semi-enclosed water body; it is a part of the river mouth area characterized by active processes of mixing of river water and seawater [Mikhailov et al., 2009; Pritchard, 1952]. During such a mixing, several transition zones are formed along the estuary bed which are critical for hydrobionts; these are so-called chorohalinicums [Aladin, 1988; Aladin, Plotnikov, 2013; Khlebovich, 1974, 1989]. Passages through chorohalinicums lead to a shift in species composition of benthic communities, their structure, trophic characteristics, and production indicators [Burkovsky, Stolyarov, 1995; Burkovsky et al., 2002; Kolpakov, 2018; Labay et al., 2022; Stolyarov, 2011, 2015, 2019a, b; Stolyarov, Burkovsky, 2018]. Estuaries are spots of concentration of specific brackish-water fauna. There, unique communities develop, and many species of fish and invertebrates feed and spawn. Estuary ecosystems are characterized by increased productivity [Kolpakov, 2018; Saf'yanov, 1987].

The estuary macrozoobenthos of Sakhalin Island, benthic communities, and their characteristics have been poorly studied [Labay et al., 2022; Safronov et al., 2000; Watercourses of Sakhalin Island, 2015]. In the most investigated estuary, that of the Manuy River, typical of most small rivers of the island, macrozoobenthos is greatly depleted compared to that of estuaries of other rivers in the Russian Far East; it lacks a clear horizontal division into zones by salinity [Labay et al., 2022]. In September 2022, the Susuya River estuary was surveyed. It is full-size compared to estuaries of small rivers on Sakhalin Island. The material of the study formed the basis of this work.

The aim of the work is to describe the main patterns of macrobenthos variability, its structure, and trophic characteristics along the salinity gradient in the full-size estuary of the Susuya River on Sakhalin Island.

MATERIAL AND METHODS

The Susuya River estuary was surveyed in September 2022 (Fig. 1, Table 1). Ten benthic transects were completed. The number of stations on the transects varied depending on the riverbed width. Thus, on transects 1–4, where the riverbed width exceeded 40 m, sampling was carried out at seven stations; on the remaining transects, with the riverbed width of less than 30 m, at five stations (near each bank at the water's edge, as well as on the fairway and on its sides). Three macrobenthos samples were taken at each station. A total of 174 samples were taken.

At depths of less than 0.3 m on pebble-gravel sediment, sampling was carried out with a folding benthometer (0.12 m^2); at greater depths on soft sediment, with a lightweight model of the small Petersen bottom grab (0.025 m^2) [Metodicheskie rekomendatsii, 2003; Rukovodstvo, 1983]. The samples were washed, fixed with 4% neutralized formalin, and labeled.

The initial analysis of the samples and species identification were carried out under laboratory conditions. The samples were washed through sieves with different mesh sizes, with the last sieve with a mesh of no more than 1 mm. After washing and identification, hydrobionts were counted, dried on filter paper until a wet spot disappeared, and weighed on electronic scales with an accuracy of tenths of a milligram. Subsequently, the quantitative data were recalculated *per* m^2.

In parallel with benthos sampling, water salinity (psu) and temperature (°C) were measured at the surface and at the bottom of the fairway with a Horiba U-5000G multi-parameter water quality checker.

The names of species and supraspecific taxa were checked on World Register of Marine Species website [2023]. The names of sediment types are given in accordance with tables E.1, E.2, and E.3 of the State Standard 25100-2011 "Soils. Classification (with Amendments)."

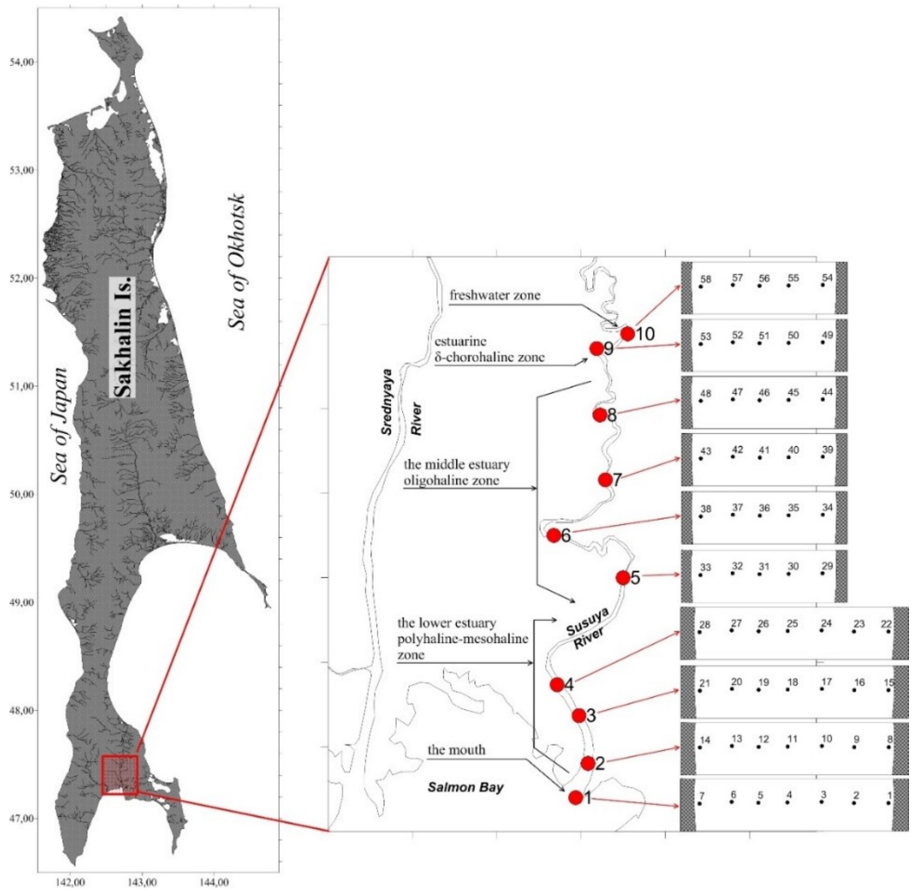

Fig. 1. Schematic map of the study area; benthos sampling sections are shown with rectangles

Table 1. Collected data

Transect No.	Distance from the mouth, km	Depth, m	Width, m	Salinity, psu	Number of stations
1	0	0 0.7	60–70	15.2 22.3	7
2	0.4	0 1.35	50–60	18.1 21.7	7
3	1.01	0 2	50–60	21.7 21.7	7
4	1.43	0 2.1	40–50	24.8 25	7
5	3.10	0 0.6	25–30	6.6 6.6	5
6	4.65	0 1.4	25–30	3.8 11.7	5
7	5.94	0 1.8	25–27	0.6 7.6	5
8	6.95	0 0.8	18–20		5
9	7.98	0 1.6	12–15		5
10	8.50	0 0.15	10–12	0.1 0.1	5

For comparison and analysis, the Shannon diversity index (entropy index) (I, bit·specimen^{-1}) was used [Shannon, 1948; Shannon, Weaver, 1949], separately for density (I_N) and biomass (I_B). Also, the ABC method (abundance/biomass comparison method) was applied [Warwick, 1986] according to the ABC index (I_{ABC}, %) [Meire, Dereu, 1990].

The expected number of species was estimated with the Chao-2 species richness extrapolation algorithm [Chao, Chiu, 2016; Petrov, Nevrova, 2012].

The study area. The Susuya River flows into Lososey Bay (the Aniva Bay, the Sea of Okhotsk), is 83 km long, and has a catchment area of 823 km^2 [Resursy, 1963]. Yuzhno-Sakhalinsk, a large administrative and industrial center, is located in the middle area of the river; this city is a source of water pollution with iron, zinc, nitrogen and phosphate groups of biogenic substances, oil products, and phenols [Chayko, 2009, 2014, 2015a, b]. In the vicinity of the Mitsulevka village, the riverbed is blocked by a dam and flows through a canal into the riverbed of the Srednyaya River. The canal was dug in 1906–1945 [Makeev, 2020; Resursy, 1964]. To date, the lower part of the riverbed, including the estuary, is isolated from the rest of the river system. This isolated part extends from the Mitsulevka River confluence to the river mouth and has a catchment area of 725 km^2 [Makeev, 2020].

According to the classification of V. Mikhailov *et al.* [2009], the Susuya River estuary is a riverbed estuary with a mouth widening (a, lower parts of riverbeds). The estuary length up to the freshwater area is almost 8.5 km (according to our data). In the upper estuary, the riverbed is 10–12 m wide; towards the mouth, the width increases to 60–70 m (our data).

The vertical distribution of water salinity in the river estuary is shown in Fig. 2. Seawater with salinity of more than 22 psu extends up to 1.5 km from the mouth. The measurements were carried out during the time interval between high and low tide; importantly, at high tide, the boundary of waters with sea salinity can occur further up the estuary. This salinity barrier separates the polyhaline estuary zone (filled with seawater) and mesohaline one (brackish-water) (the boundaries of waters with different salinity are given according to [Aladin, 1988; Aladin, Plotnikov, 2013; Khlebovich, 1974, 1989]). Brackish water with salinity from 5–7 psu (the α-chorohaline boundary) to 22–26 psu (the β-chorohaline boundary) fills the estuary for more than 3 km from the mouth. Below the 6th km and to 3 km, throughout the entire water area of the estuary reach, there is a vertical salinity gradient. The lower layer corresponds to the α-chorohaline boundary, while the narrow upper layer is freshened (oligohaline). A similar vertical distribution of salinity is revealed for typical estuaries of Sakhalin Island rivers [Labay et al., 2022]. From the 6th km upstream, an oligohaline zone is noted for about 1 km. At a distance of approximately 7 km from the mouth, it is limited by the δ-chorohalinicum (0.5–2.0 psu) which extends upward to the last river riffle (transect 10). Above the riffle, the river water is fresh (about 0 psu).

In terms of distribution of water salinity, five estuary zones are distinguished: the mouth filled with seawater (polyhaline zone); the lower estuary polyhaline–mesohaline zone; the middle estuary oligohaline zone; the upper estuary δ-chorohaline zone, and the freshwater zone. The middle estuary zone is the longest: it extends along the riverbed for almost 4 km. The lower and upper estuary zones are shorter, 1–2 km each. The obtained scheme is similar to the typification of river estuaries developed by N. Kolpakov [2018]. In contrast to the typical estuaries of Sakhalin Island, there is a clearly defined lower estuary zone, about 1.5 km long, filled along its entire vertical with water with sea salinity (in other estuaries, seawater penetrates no further than 100–200 m from the mouth) [Labay et al., 2022]. Apparently, this phenomenon can be explained by redistribution of the river flow in the middle reach into the riverbed of the Srednyaya River [Makeev, 2020; Resursy, 1964]. As a result, with the same size of the estuary bed, the volume of river runoff has significantly decreased, and this mediated a noticeable penetration of seawater up the riverbed at the present time.

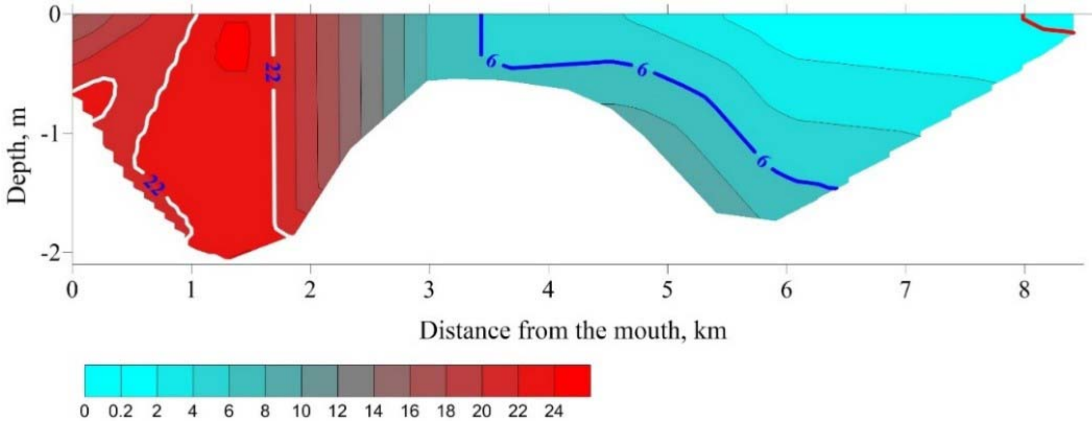

Fig. 2. Vertical distribution of water salinity along the Susuya River estuary on 15.09.2022

At the mouth, the bottom is covered with fine sand with silt and clay, and in the fairway, with sand (about 80%) with large pebbles. Upstream, in the middle and lower estuary zones, the river banks are clayey or sandy-silty. In the mouth reach, organic silt and clay occur; less often, silt is registered. At the boundary between the lower estuary and middle estuary, the bottom sediment is represented by sands of various sizes with pebbles and silts. In the upper estuary, on the reach, the banks are silty, while with increasing depth, the bottom sediment changes to silts. The river riffle which separates the freshwater zone of the riverbed and the δ-chorohaline zone, is pebble-gravel with an admixture of sand.

During the study period, the current was expressed only in the riffle (transect 10): there, the current velocity varied by stations within 0.15–0.38 $m \cdot s^{-1}$. Already on transect 9, the value did not exceed 0.01 $m \cdot s^{-1}$. On other transects, there was no unidirectional current.

On transects 2 and 3, thickets of macrophytes, chiefly *Zostera* ones, were noted along the coast. There, aggregations of dead macrophytes were also observed, probably brought in by tide.

RESULTS AND DISCUSSION

The river estuary is inhabited by brackish-water and marine fish species. These are the saffron cod *Eleginus gracilis* (Tilesius, 1810); smelts of the genus *Hypomesus*, Japanese ones *H. japonicus* (Brevoort, 1856) and *H. nipponensis* McAllister, 1963, as well as the pond one *H. olidus* (Pallas, 1814); a three-spined stickleback *Gasterosteus nipponicus* (Higuchi, Sakai et Goto, 2014); nine-spined sticklebacks, *Pungitius pungitius* (Linnaeus, 1758) and *P. sinensis* (Guechenot, 1869); a goby *Gymnogobius urotaenia* (Hilgendorf, 1879); a sculpin *Megalocottus taeniopterus* (Kner, 1868); the starry flounder *Platichthys stellatus* (Pallas, 1787); the eastern viviparous blenny *Zoarces elongatus* (Kner, 1868); and *Brachyopsis segaliensis* (Tilesius, 1809). In the early XX century, the Sakhalin sturgeon *Acipenser mikadoi* Hilgendorf, 1892 was abundant in the estuary; to date, this species has completely disappeared [Makeev, 2020; Shmidt, 1905].

Distribution of macrobenthos. Earlier, unique species of benthic invertebrates were discovered in the Susuya River estuary, absent from the typical estuaries of Sakhalin Island rivers. There, a crab *Deiratonotus cristatum* (De Man, 1895) and an amphipod *Melita shimizui sakhalinensis* Labay, 2016 were described for the first time in Russia [Labai, 2004; Labay, 2016, 2021; Marin, 2017].

The species list of the macrobenthos of the Susuya River estuary includes 58 species of benthic invertebrates and cyclostomes (Table 2). The expected number of species Chao-2 was 65. Accordingly, 89% of the possible maximum number of species were found in the samples. The most represented group is Malacostraca, 22 species (amphipods, 11 species). A significant difference from other estuaries of the island is the developed fauna of decapods, 7 species [Labay, 2011, 2021; Labay et al., 2022; Watercourses of Sakhalin Island, 2015]. Insects, mostly chironomids, cover 15 species. Polychaetes are diverse as well, 9 species. Molluscs are represented by 7 species (3 species of gastropods and 4 species of bivalves), and this makes the Susuya River estuary more similar to other estuaries of large and medium rivers in the Russian Far East [Kolpakov, 2018; Komendantov, Orlova, 2003; Watercourses of Sakhalin Island, 2015]. Other groups include 1–2 species each. A distinctive feature of the Susuya River estuary is the noticeable representation of typical lagoon brackish-water and marine species absent from other estuaries of the island: *Fluviocingula nipponica* Kuroda & Habe, 1954, *Assiminea lutea* A. Adams, 1861, *Batillaria attramentaria* (G. B. Sowerby II, 1855), *Macoma balthica* (Linnaeus, 1758), *Ampithoe lacertosa* Spence Bate, 1858, *Eogammarus possjeticus* (Tzvetkova, 1967), *Hemigrapsus takanoi* Asakura & Watanabe, 2005, and *Upogebia major* (De Haan, 1841) [Labay, 2015; Reservoirs of Sakhalin Island, 2014].

Table 2. The species composition of the Susuya River estuary

No.	Species	Transect No.									
		1	2	3	4	5	6	7	8	9	10
	Phylum Nemertea										
1	Nemertea indet.	+	+	+	+	+	+	+	–	–	+
	Phylum Annelida										
	Class Polychaeta										
2	Polychaeta indet.	–	+	–	–	–	–	–	–	–	–
	Order Phyllodocida										
3	agg. *Eteone flava* (Fabricius, 1780)	+	+	+	+	+	+	–	–	–	–
4	*Glycera capitata* Örsted, 1843	+	–	–	–	–	–	–	–	–	–
5	*Goniada maculata* Örsted, 1843	+	+	+	+	–	–	–	–	–	–
6	*Hediste japonica* (Izuka, 1908)	+	+	+	+	+	+	+	+	+	+
	Order Spionida										
7	*Aonides oxycephala* (Sars, 1862)	–	–	–	–	+	–	–	–	–	–
8	*Polydora* indet.	+	+	+	–	–	–	–	–	–	–
	Infraclass Scolecida										
9	Capitellidae indet.	+	+	+	+	+	+	+	+	–	–
10	*Ophelia limacina* (Rathke, 1843)	+	–	–	–	–	–	–	–	–	–
	Class Clitellata										
	Subclass Oligochaeta										

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No.	Species	Transect No.									
		1	2	3	4	5	6	7	8	9	10
	Order Tubificida										
11	*Limnodrilus hoffmeisteri* f. *typica* Claparède, 1862	–	+	+	+	+	+	+	+	+	+
12	*Tubifex tubifex* (O. F. Müller, 1773)	–	–	–	–	–	–	–	–	+	+
	Subclass Hirudinea										
13	Hirudinea indet.	+	–	–	–	–	–	–	–	–	–
	Phylum Mollusca										
	Class Gastropoda										
	Order Littorinimorpha										
14	*Fluviocingula nipponica* Kuroda & Habe, 1954	+	+	+	+	+	–	–	–	–	–
15	*Assiminea lutea* A. Adams, 1861	+	+	+	+	+	+	+	–	–	–
	Order Caenogastropoda										
16	*Batillaria attramentaria* (G. B. Sowerby II, 1855)	+	+	–	+	–	–	–	–	–	–
	Class Bivalvia										
	Order Cardiida										
17	*Macoma balthica* (Linnaeus, 1758)	+	+	+	+	–	–	–	+	–	–
	Order Nuculanida										
18	*Nuculana pernula* (O. F. Müller, 1779)	+	+	–	–	–	–	–	–	–	–
	Order Venerida										
19	*Corbicula japonica* Prime, 1864	+	+	–	+	+	+	+	+	–	+
	Superorder Anomalodesmata										
20	*Exolaternula liautaudi* (Mittre, 1844)	+	+	+	+	–	–	–	–	–	–
	Phylum Arthropoda										
	Subphylum Crustacea										
	Superclass Multicrustacea										
	Class Malacostraca										
	Order Cumacea										
21	*Bodotria parva* Calman, 1907	+	+	–	–	–	–	–	–	–	–
	Order Amphipoda										
22	*Ampithoe lacertosa* Spence Bate, 1858	+	+	+	+	–	–	–	–	–	–
23	*Caprella algaceus* Vassilenko, 1967	+	+	–	–	–	–	–	–	–	–
24	*Crassicorophium crassicorne* (Bruzelius, 1859)	+	–	–	+	–	–	–	–	–	–
25	*Eogammarus kygi* (Derzhavin, 1923)	–	–	–	–	–	–	–	–	–	+
26	*Eogammarus possjeticus* (Tzvetkova, 1967)	+	–	–	–	–	–	–	–	–	–
27	*Eogammarus tiuschovi* (Derzhavin, 1927)	+	+	+	+	+	–	–	–	–	–
28	*Ischyrocerus elongatus* Gurjanova, 1938	+	–	–	–	–	–	–	–	–	–
29	*Kamaka derzhavini* Gurjanova, 1951	+	+	+	+	–	–	–	–	–	–
30	*Kamaka kuthae* Derzhavin, 1923	–	–	–	–	–	+	+	+	–	–
31	*Melita shimizui sakhalinensis* Labay, 2016	+	+	–	+	–	–	–	–	–	–
32	*Melita* sp.	–	–	–	–	+	+	+	–	–	+
	Order Isopoda										
33	*Gnorimosphaeroma kurilense* Kussakin, 1974	–	–	–	–	–	–	–	–	–	+
34	*Gnorimosphaeroma ovatum* (Gurjanova, 1933)	+	+	+	+	+	+	–	–	–	–

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No.	Species	Transect No.									
		1	2	3	4	5	6	7	8	9	10
	Order Mysida										
35	*Neomysis awatschensis* (Brandt, 1851)	+	+	+	+	+	+	+	–	+	+
	Order Decapoda										
36	*Crangon amurensis* Bražnikov, 1907	+	+	–	–	+	+	+	–	–	–
37	*Deiratonotus cristatum* (De Man, 1895)	–	+	+	–	+	+	–	–	–	–
38	*Eriocheir japonica* (De Haan, 1835)	+	–	–	–	–	–	–	+	–	+
39	*Hemigrapsus longitarsis* (Miers, 1879)	–	–	+	–	–	–	–	–	–	–
40	*Hemigrapsus takanoi* Asakura & Watanabe, 2005	+	–	–	–	–	–	–	–	–	–
41	*Palaemonetes sinensis* (Sollaud, 1911)	–	–	–	–	–	–	–	+	–	–
42	*Upogebia major* (De Haan, 1841)	–	+	+	+	–	–	–	–	–	–
	Superclass Allotriocarida										
	Class Hexapoda										
	Order Diptera										
43	Ceratopogonidae indet. (larv.)	–	–	–	–	–	–	–	–	–	+
44	*Chironomus (Lobochironomus) dorsalis* (Meigen, 1818) (larv.)	–	–	–	–	–	–	–	+	+	+
	Chironomus (Lobochironomus) dorsalis (Meigen, 1818) (pupa)	–	–	–	–	–	–	–	–	+	+
45	*Chironomus salinarius* Kieffer, 1915 (larv.)	–	–	–	+	–	–	+	+	–	–
46	*Cladotanytarsus* gr. *mancus* (Walker, 1856) (larv.)	–	+	–	+	–	–	–	–	–	–
47	*Dicrotendipes* indet. (larv.)	–	–	–	–	–	–	–	–	–	+
48	*Glyptotendipes cauliginellus* (Kieffer, 1913) (larv.)	–	–	–	–	–	–	–	+	+	+
49	*Glyptotendipes* gr. *gripekoveni* (Kieffer, 1913) (larv.)	–	–	–	–	–	–	–	–	–	+
50	*Glyptotendipes* gr. *paripes* (Edwards, 1929) (larv.)	–	–	–	–	–	–	–	–	+	–
51	*Paratendipes albimanus* (Meigen, 1804) (larv.)	–	–	–	–	–	–	–	–	+	+
52	*Polypedilum* indet. (pupa)	–	–	–	–	–	–	–	+	–	–
53	*Polypedilum (Tripodura) scalaenum* (Schrank, 1803) (larv.)	–	–	–	–	–	–	–	+	–	–
54	*Psectrocladius* gr. *zetterstedti* Brundin, 1949 (larv.)	–	–	–	–	–	–	–	–	–	+
55	*Sergentia baueri* Wulker, Kiknadze & Kerkis, 1999 (larv.)	–	–	–	–	–	–	–	+	+	–
	Sergentia baueri Wulker, Kiknadze & Kerkis, 1999 (pupa)	–	–	–	–	–	–	–	–	+	–
56	*Stictochironomus pictulus* (Meigen, 1830) (larv.)	–	–	+	+	+	+	+	+	+	+
57	*Trissopelopia longimana* (Staeger, 1839) (larv.)	–	–	–	–	–	–	–	+	+	+
	Phylum Chordata										
	Infraphylum Agnatha										
	Class Petromyzonti										
	Order Petromyzontiformes										
58	*Lethenteron reissneri* (Dybowski, 1869)	–	–	–	–	–	–	–	+	–	–
Total number of species		30	27	20	23	16	14	12	17	12	20
Expected number of species Chao-2		37	41	20	27	22	17	13	18	15	25

Species richness changes much with distance from the mouth: from 30 species *per* section on transect 1 at the river mouth to 12 species on transect 7 with water corresponding to the α-chorohaline boundary at the bottom and to 20 species *per* section on transect 10 at the transition to the freshwater area of the riverbed (Fig. 3A). A drop in the indicator value is recorded from the mouth transect with sea salinity to the α-chorohaline boundary, and this corresponds to provisions of the theory of critical salinity [Khlebovich, 1974, 1989]. The expected number of species Chao-2 was also the highest in the area of effect of polyhaline (marine) water on transects 1 and 2, while the number of species found in this part of the riverbed was 66–81% of the expected one (Table 2). In the brackish-water (mesohaline), oligohaline, and δ-chorohaline zones of the estuary, the indicator varied within 73–100% of the expected number of species with a minimum on transect 7. In the freshwater part of the estuary, Chao-2 increased and was equal to 25 species (80% of species were registered).

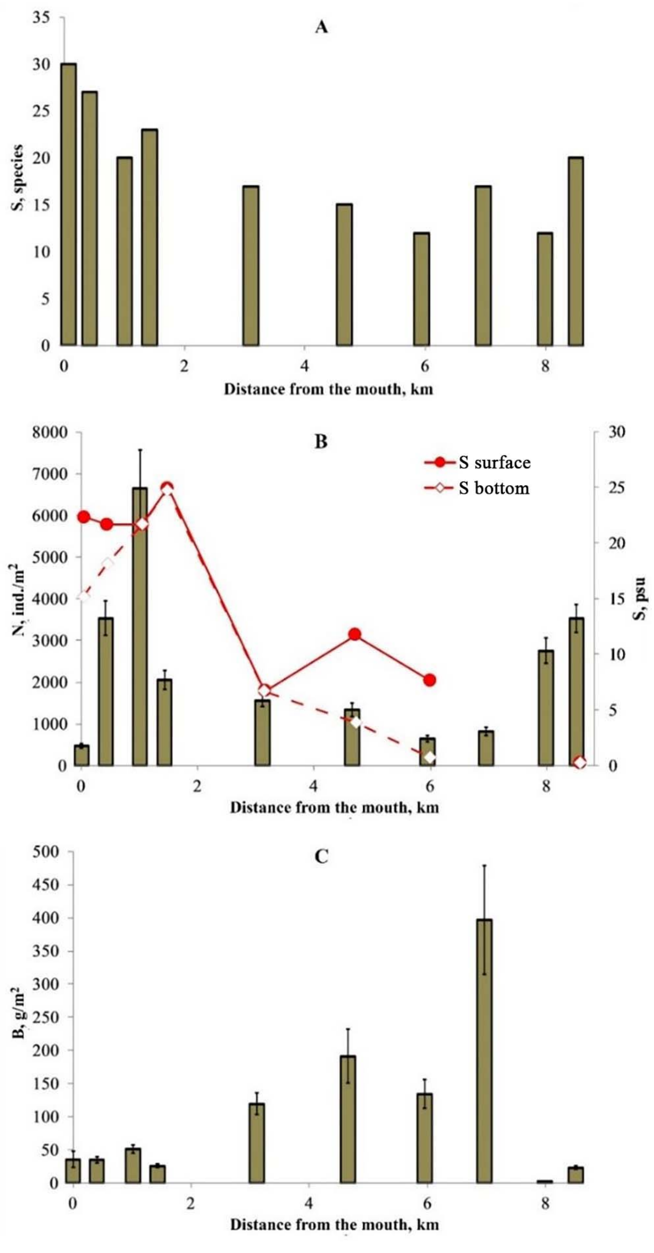

Fig. 3. Variability of macrozoobenthos abundance along the Susuya River estuary: A, number of species *per* section; B, total density and salinity (S); C, total biomass (error bars correspond to the error of the mean)

In the lower estuary zone, both estuary-specific hydrobionts and coastal-marine and lagoon species were revealed. The first ones cover a bivalve *Exolaternula liautaudi* (Mittre, 1844) and amphipods *Kamaka derzhavini* Gurjanova, 1951 and *M. shimizui sakhalinensis* [Labay, 2021]. The second ones include polychaetes *Eteone flava* (Fabricius, 1780), *Glycera capitata* Örsted, 1843, *Goniada maculata* Örsted, 1843, and *Ophelia limacina* (Rathke, 1843); gastropods *F. nipponica*, *As. lutea*, and *B. attramentaria*; bivalves *M. balthica* and *Nuculana pernula* (O. F. Müller, 1779); a cumacean *Bodotria parva* Calman, 1907; amphipods *Am. lacertosa*, *Caprella algaceus* Vassilenko, 1967, *Crassicorophium crassicorne* (Bruzelius, 1859), *Eo. possjeticus*, and *Ischyrocerus elongatus* Gurjanova, 1938; crabs *Hemigrapsus longitarsis* (Miers, 1879) and *H. takanoi*; and *Up. major*.

Typical representatives of the brackish-water fauna of Sakhalin in the middle estuary zone cover an isopod *Gnorimosphaeroma ovatum* (Gurjanova, 1933) and a crab *D. cristatum* [Labay, 2015, 2021; Reservoirs of Sakhalin Island, 2014; Watercourses of Sakhalin Island, 2015].

Indicators of oligohaline waters are a polychaete *Hediste japonica* (Izuka, 1908), a bivalve *Corbicula japonica* Prime, 1864, amphipods *Melita* sp., and a shrimp *Palaemonetes sinensis* (Sollaud, 1911) [Labay, 2021; Watercourses of Sakhalin Island, 2015]. The first one was also registered in the brackish-water zone of the estuary.

Several species were euryhaline and occurred in all the zones. Those are a polychaete *H. japonica*, an oligochaete *Limnodrilus hoffmeisteri* f. *typica* Claparède, 1862, a mysid *Neomysis awatschensis* (Brandt, 1851), a sand shrimp *Crangon amurensis* Bražnikov, 1907, and a mitten crab *Eriocheir japonica* (De Haan, 1835).

From the river mouth (transect 1) to the center of the lower estuary (transect 3), an increase in macrobenthos density is recorded, from (476 ± 59) to (6,653 ± 915) ind.·m^{-2} (Fig. 3B). In the middle estuary zone, the value drops sharply, to (653 ± 72) ind.·m^{-2} on transect 7 near the α-chorohaline boundary. In the upper estuary zone, the density rises again: to a maximum of (3,529 ± 336) ind.·m^{-2} on transect 10.

In the lower estuary zone, the indicator is formed by polychaetes (7.7–47.4%), gastropods (11.4–50.0%), and amphipods (21.2–67.8%). Out of polychaetes, the highest density is revealed for *H. japonica* and Capitellidae indet.; out of gastropods, for *F. nipponica*; and out of amphipods, for *K. derzhavini*, *M. shimizui sakhalinensis*, and *Eogammarus tiuschovi* (Derzhavin, 1927).

In the middle estuary zone, the main contributors to the total density are polychaetes, 45.7–63.7%; amphipods account for 7.7–16.1%; and the role of oligochaetes (0.6–29.7%) and isopods (up to 11.0%) increases. The density of polychaetes is formed by *H. japonica* and Capitellidae indet.; oligochaetes, by *L. hoffmeisteri*; amphipods, by *Melita* sp.; and isopods, by *Gn. ovatum*.

On the transects of the upper estuary zone, oligochaetes (9.9–49.7%) and dipterans (23.3–89.7%) prevail in density. The most significant species of oligochaetes is *L. hoffmeisteri*; the key species of dipterans are chironomids *Glyptotendipes cauliginellus* (Kieffer, 1913), *Paratendipes albimanus* (Meigen, 1804), *Sergentia baueri* Wulker, Kiknadze & Kerkis, 1999, *Stictochironomus pictulus* (Meigen, 1830), and *Trissopelopia longimana* (Staeger, 1839).

Four peaks are observed in the distribution of the total biomass throughout the estuary (Fig. 3C). The first one characterizes the lower estuary zone: transect 3, (51.2 ± 5.7) g·m^{-2}. The second peak is confined to the middle estuary zone: transect 6, (190.5 ± 41.2) g·m^{-2}. The third one is recorded in the upper estuary: transect 8, (397.5 ± 82.0) g·m^{-2}. The fourth peak is noted at the riffle separating the estuary from the freshwater zone of the riverbed: (23.4 ± 2.78) g·m^{-2}. The area of critically low biomass is revealed on transect 9: (2.67 ± 0.261) g·m^{-2}.

The contribution of different macrozoobenthos groups to the total biomass along the estuary is shown in Fig. 4. At the river mouth, in terms of biomass, decapods prevail (95.5%) represented chiefly by crabs *H. takanoi* and *Er. japonica* (Table 3).

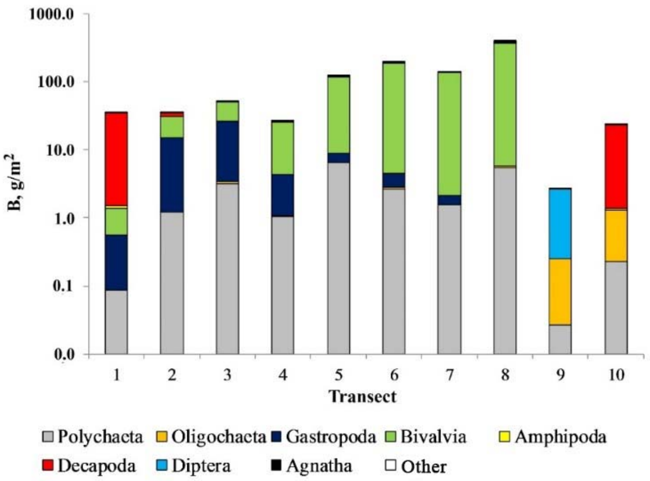

Fig. 4. The biomass of the main taxonomic groups of macrozoobenthos

Table 3. Characteristics of salinity zones (S) and changes in macrozoobenthos along the Susuya River estuary

Indicator	Zone				
	mouth (transect 1)	lower estuary polyhaline–mesohaline (transects 2–4)	middle estuary oligohaline (transects 5–8)	upper estuary δ-chorohaline (transect 9)	freshwater (transect 10)
$S_{surface}$, psu	15.2	18.1–24.8	0.6–6.6	0.2	0.1
S_{bottom}, psu	22.3	21.7–25	6.6–11.7	1	0.1
Number of species *per* transect	30	20–27	12–17	12	20
Chao-2	37	20–41	13–22	15	25
Abundance (N), ind.·m^{-2}	476 ± 59	2,051–6,653	653–1,561	2,760 ± 306	3,529 ± 336
Biomass (B), g·m^{-2}	35.7 ± 12.6	26.2–51.2	119.3–397.5	2.67 ± 0.26	23.4 ± 2.78
Key density groups	Amphipoda, Gastropoda	Gastropoda, Polychaeta, Amphipoda	Polychaeta, Amphipoda, Oligochaeta, Diptera, Isopoda	Diptera, Oligochaeta	Oligochaeta, Diptera
Key biomass groups	Decapoda	Bivalvia, Gastropoda	Bivalvia, Polychaeta	Diptera, Oligochaeta	Decapoda
Key species	*Eriocheir japonica*, *Hemigrapsus takanoi*	*Fluviocingula nipponica*, *Macoma balthica*, *Hediste japonica*	*Corbicula japonica*, *Hediste japonica*	*Chironomus dorsalis*, *Sergentia baueri*, *Glyptotendipes cauliginellus*, *Limnodrilus hoffmeisteri*	*Eriocheir japonica*, *Limnodrilus hoffmeisteri*, *Stictochironomus pictulus*
I_N, bit·specimen^{-1}	1.97	1.77–2.05	1.24–1.86	1.57	1.35
I_B, bit·specimen^{-1}	0.71	0.85–1.62	0.12–0.42	1.54	0.40
I_{ABC}, %	39.3	14.6–25.7	14.5–35.9	15.6	11.8

Upstream, there is a shift in prevailing taxa. Specifically, on transects 2–4, the key contributors are bivalves, mostly *M. balthica* (42.5–81.4%), and gastropods, mainly *F. nipponica* (12.2–45.1%); less significant contributors are polychaetes (3.4–6.2%) and decapods (0.1–11.3%). On transects 5–8, in the middle estuary oligohaline zone, the biomass is formed by bivalves represented almost by *C. japonica* alone (90.8–98.1%). On transect 9 indicating the transition from the upper estuary oligohaline zone to the freshwater one, the greatest contribution (90.0%) is that of dipterans (chironomids). On transect 10, on the freshwater riffle, the main contributors are again decapods represented by *Er. japonica* alone (91.7%).

The distribution of areas critical for bottom hydrobionts along the river estuary is estimated by the Shannon diversity index (Fig. 5A). For typical bottom communities, where the biomass is chiefly concentrated in several key species, *I* values in terms of biomass are always lower than those in terms of density [Labay et al., 2022]. The ratio of *I* values changes to the opposite at critical points indicating the transition from one type of community to another. In the Susuya River estuary, index ratios close to critical ones characterize transect 2 (the pre-estuary) and transect 9 (the border of the upper estuary oligohaline zone and the freshwater area). More critical points are revealed in the distribution of the ABC index (Fig. 5B): its values are low on transects 2 (β-chorohalinicum), 5 (α-chorohalinicum), and 9–10 (δ-chorohalinicum). The location of the lower critical (boundary) point on transect 2 is natural and characterizes the boundary between the lower estuary zone and the marine area of the mouth. The upper critical point (transect 10) is observed 520 m upstream than it is recorded by the total biomass and *I* (transect 9). Thus, by biological indicators, the boundary between the upper estuary oligohaline zone and the freshwater area of the riverbed extends for several hundred meters. A decrease in I_{ABC} on transect 5 evidences for its proximity to the α-chorohaline boundary in terms of salinity.

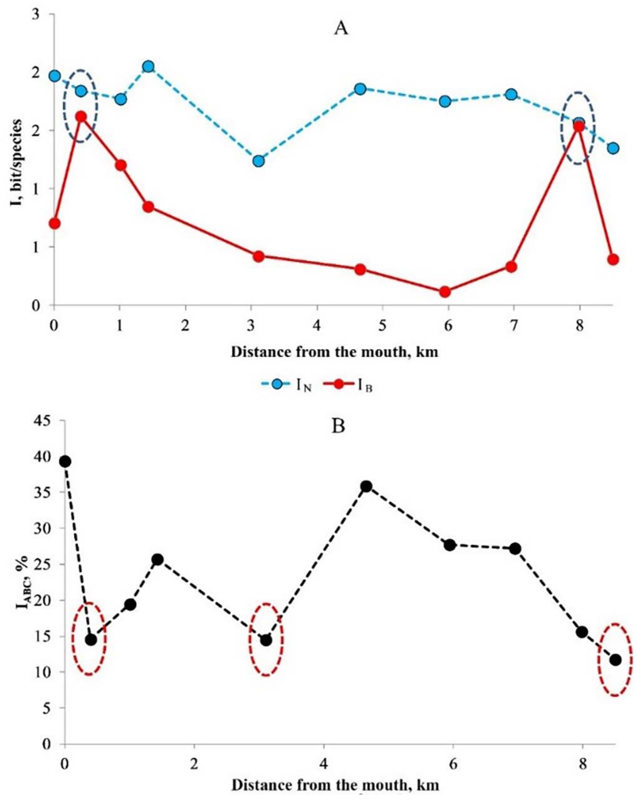

Fig. 5. Variability of the Shannon–Wiener diversity index *I* (A) and ABC index I_{ABC} (B) in macrobenthos along the Susuya River estuary

Conclusion. In the Susuya River estuary, five zones are clearly distinguished by the hydrological regime and by distribution of macrobenthos and main communities: the mouth, the lower estuary polyhaline–mesohaline zone, the middle estuary oligohaline zone, the upper estuary δ-chorohaline zone, and the freshwater zone. In the middle estuary zone, a vertical salinity gradient from 0.8 to 7.0 (11.0) psu is recorded. The river estuary is limited from above by a pebble-gravel riffle with freshwater.

The species composition of macrozoobenthos covers 58 species. Each of the identified zones has its own composition of hydrobionts.

An increase in the density of macrozoobenthos is registered from the river mouth to the lower estuary zone, with a subsequent drop in the value at the α-chorohaline boundary. In the upper estuary zone, the specific abundance sharply rises to a maximum at the freshwater riffle. In the lower estuary zone, the indicator is formed mostly by polychaetes, gastropods, and amphipods. In the middle estuary zone, the main contribution to the total density is made by polychaetes and amphipods; the role of oligochaetes and isopods increases as well. On the transects of the upper estuary, oligochaetes and dipterans are most significant in density.

Four peaks are observed in the distribution of the total biomass along the estuary: in the lower estuary, in the middle estuary zone, in the upper estuary oligohaline zone, and on the riffle separating the estuary from the freshwater area of the riverbed. The area of critically low biomass is confined to the δ-chorohalinicum in the upper estuary zone. In the river mouth, decapods are the most significant in terms of biomass. In the lower estuary, the main contributors to the total density are bivalves, mainly *Macoma balthica*, and gastropods, mostly *Fluviocingula nipponica* (with a smaller contribution of polychaetes and decapods). In the middle estuary oligohaline zone, the basis of the indicator is formed by bivalves represented almost by *Corbicula japonica* alone. In the δ-chorohalinicum, the key contributors are dipterans (chironomids). In the freshwater riffle, decapods become the main group again; those are represented by *Eriocheir japonica* alone.

Based on abundance of macrobenthos and structural indices, the boundaries between the mouth and the lower estuary zone are clearly distinguished, α-chorohalinicum and δ-chorohalinicum. The boundary between the upper estuary oligohaline zone and freshwater zone extends for several hundred meters along the Susuya River estuary.

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МАКРОЗООБЕНТОС ЭСТУАРИЯ РЕКИ СУСУЯ (ОСТРОВ САХАЛИН): I. ГИДРОЛОГИЧЕСКАЯ ХАРАКТЕРИСТИКА ЭСТУАРИЯ, ВИДОВОЙ СОСТАВ И РАСПРЕДЕЛЕНИЕ МАКРОЗООБЕНТОСА

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Описаны видовой состав, структура, количественные показатели и особенности распределения вдоль русла реки макрозообентоса эстуария реки Сусуя (остров Сахалин). По гидрологическим характеристикам и показателям макробентоса выделены основные биотопические зоны эстуария: устье (полигалинная), нижнеэстуарная полигалинно-мезогалинная, среднеэстуарная олигогалинная, верхнеэстуарная δ-хорогалинная и пресноводная. В эстуарии реки обнаружены 58 видов донных гидробионтов. Основу видового состава формируют высшие раки — 22 вида. К амфибиотическим насекомым относятся 15 видов, к полихетам — 9, к моллюскам — 7. Прочие группы представлены 1–2 видами. Каждой из выделенных зон соответствует специфический состав донных гидробионтов. Видовое богатство снижается от устьевого разреза с морской солёностью воды (30 видов) до α-хорогалинной границы (12 видов), что соответствует положениям теории критической солёности. При переходе в пресноводную часть русла значение возрастает до 20 видов. Плотность макробентоса увеличивается от (476 ± 59) экз.·м$^{-2}$ в устье реки до (6653 ± 915) экз.·м$^{-2}$ в центре нижней части эстуария. Минимум плотности, (653 ± 72) экз.·м$^{-2}$, характеризует α-хорогалинную границу, а максимум, (3529 ± 336) экз.·м$^{-2}$, — верхнеэстуарную зону. В нижней части эстуария основу плотности формируют полихеты, гастроподы и амфиподы; в среднеэстуарной зоне — полихеты, амфиподы и олигохеты; в верхнеэстуарной зоне — олигохеты и двукрылые насекомые. Отмечены четыре участка с высокой биомассой макрозообентоса: нижняя часть эстуария, (51,2 ± 5,7) г·м$^{-2}$; среднеэстуарная зона, (190,5 ± 41,2) г·м$^{-2}$; верхняя часть, (397,5 ± 82,0) г·м$^{-2}$; перекат, отграничивающий эстуарий от пресноводной части русла, (23,4 ± 2,78) г·м$^{-2}$. В устье реки основу биомассы формируют десятиногие раки. Выше по течению самый существенный вклад вносят двустворчатые моллюски, преимущественно *Macoma balthica*, и гастроподы, в основном *Fluviocingula nipponica*. В средней олигогалинной зоне наиболее значимы двустворчатые моллюски, представленные почти исключительно *Corbicula japonica*. На границе олигогалинной и верхнеэстуарной зон преобладают двукрылые насекомые (хирономиды). На пресноводном перекате главной группой опять становятся десятиногие раки, представленные исключительно крабом *Eriocheir japonica*. По показателям обилия макробентоса и структурным индексам чётко выделяются границы между устьем и нижнеэстуарной зоной, α-хорогалиникум и δ-хорогалиникум. Граница между верхнеэстуарной олигогалинной и пресноводной зонами имеет протяжённость несколько сот метров вдоль эстуария.

Ключевые слова: эстуарий, солёность, макрозообентос, плотность, биомасса, остров Сахалин