Distribution and seasonal changes in fish abundance in the estuary of the Razdol'naya River (Peter the Great Bay), Sea of Japan

Article *in* Journal of Ichthyology · November 2010

DOI: 10.1134/S0032945210060032

2 authors:

Nikolai V. Kolpakov
Sakhalin branch of Russian Federal Research Institute of Fisheries and Oceanogra…

Pavel Milovankin
Scientific Research Institute of Epidemiology and Microbiology named after G. P. …

ISSN 0032-9452, Journal of Ichthyology, 2010, Vol. 50, No. 6, pp. 445–459. © Pleiades Publishing, Ltd., 2010.
Original Russian Text © I.V. Kolpakov, P.G. Milovankin, 2010, published in Voprosy Ikhtiologii, 2010, Vol. 50, No. 4, pp. 351–365.

Distribution and Seasonal Changes in Fish Abundance in the Estuary of the Razdol'naya River (Peter the Great Bay), Sea of Japan

I. V. Kolpakov[a] and P. G. Milovankin

Pacific Research Fishery Center (TINRO-Center), tupik Shevchenko 4, Vladivostok, 690600 Russia;
e-mail: kolpakov@tinro.ru

Received April 29, 2009

Abstract—The distribution and seasonal dynamics of fish abundance in the estuary of the Razdol'naya River (Peter the Great Bay) depending on several abiotic factors are considered. It is established that fish biomass increases with an increase in salinity and decrease in water temperature (both in space and time). Freshwater stenohaline species dominate in the upper part of the estuary, semianadromous and freshwater euryhaline species dominate in the middle part, and semianadromous and marine species dominate in the lower part. The seasonal succession of ichthyocenosis includes two periods: warm (May–October) and cold (November–April). The warm period is characterized by a low biomass (4–10 g/m^2) and maximum species richness (22–29 species) against the background of a decrease of the penetration into the estuary of high-saline waters and an increase in the water discharge, turbidity, and temperature. Freshwater species dominate in catches, and subtropical migrants appear. In the cold period, species richness is minimal (2–12 species), and biomass is, on the contrary, very high (on average, 71–274 g/m^2); water temperature and discharge are minimal. In catches, the proportion of semianadromous and marine species is maximum.

DOI: 10.1134/S0032945210060032

Key words: estuary, Razdol'naya River, fish distribution.

Estuary ecosystems located in the zone of contact of marine and fresh waters are characterized by a very high level of producing organic matter and play an important role in the economics of coastal areas. In many respects, the interest of researchers in the study of similar ecosystems and, in particular, fish communities from estuaries, is based on it. The biocenological studies of estuary ecosystems are rather actively carried out in many areas of the planet: in South Africa, Western Europe, and North America (Whitfield, 1999; Mathieson et al., 2000; Visintainer et al., 2006; Franco et al., 2008; et al.). In Russian waters of the northwestern part of the Pacific Ocean, such studies are performed locally; they are mainly related to the needs of mariculture and are oriented at the study of the early marine period of salmon life (Karpenko, 1998; Ivankov et al., 1999; Maksimenko, 2002; Kafanov et al., 2003).

The water area of Peter the Great Bay (including its estuary zones) is an area of the most active commercial activity in the northwestern part of the Sea of Japan and, correspondingly, to the greatest degree, is subjected to the anthropogenic pollution (Ogorodnikova, 2001). One of the largest rivers of the Bay, Razdol'naya, in its lower course forms a comparatively vast estuary that has a certain fish-cultural importance (Kazanskii, 1971). The composition, structure, and spatio-temporal dynamics of estuary ichthyocenoses of the Razdol'naya River have not been almost studied up to the present time. This study is to fill this gap.

MATERIAL AND METHODS

Quantitative collections of fish were performed in the lower course of the Razdol'naya River at a distance of 24 km from the estuary in 2005–2008 (Fig. 1). Fish were seined with a fry net (length of 15 m, height of 2.5 m, mesh size in the cod-end of 5 mm). Juveniles and fish species whose individuals in the definitive state have small sizes were mainly seined. In winter time (under ice), fish were seined with a drag seine with a length of 40–150 m and a mesh of 10–20 mm in the cod-end. A total of 318 seinings with fry and drag seines were performed. The fishing power coefficient (FC) of the nets is taken equal to be unity.

For the characteristics of the community, we used the following integral characteristics: species richness (S), biomass (g/m^2), and polydominance index ($S_{\lambda'}$)—relation to the unity of Simpson concentration measure: $S_{\lambda'} = (\sum_i p_i^2)^{-1}$, ($i = 1, 2, 3 \ldots S$) $1 \le S_{\lambda'} \le \infty$, where p_i is the proportion of this species in the general population including S species (Pesenko, 1982). The dendrogram was compiled by the UPGMA method (nonweighted pair-group average); measure of differ-

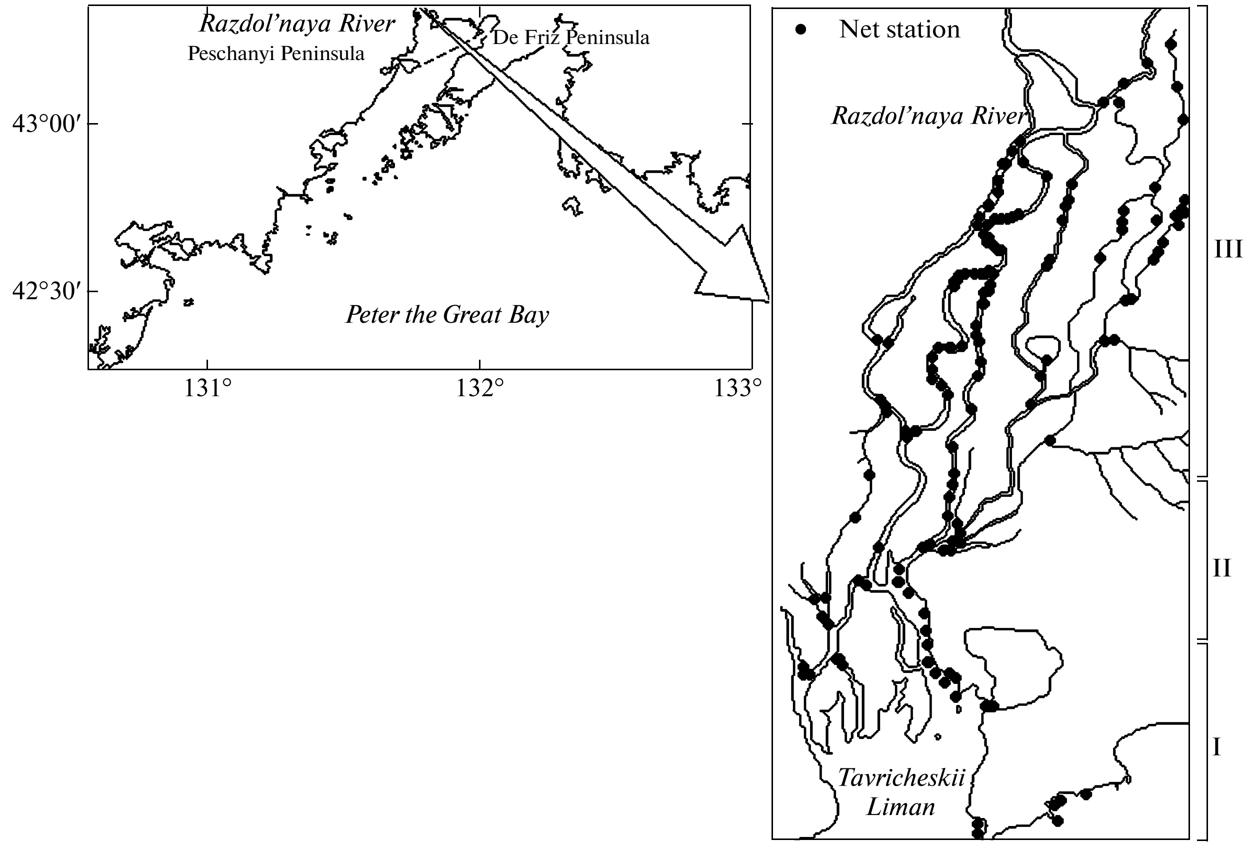

Fig. 1. Map-scheme of study area. (I) low site; (II) middle site; (III) upper site. The boundary of the area for which data on species fish composition are generalized is shown by a dotted line.

ences was the Euclidean distance. For selection of the adequate degree of fractionality of the obtained clusters, the criterion of significant similarity was used that was calculated as the upper 95% confidence boundary of the average (for the entire combination of stations) of similarity between the samples (Burkovskii et al., 2002).

RESULTS AND DISCUSSION

Brief characteristic of the Razdol'naya River. Razdol'naya (before 1972, Suifun) is the second by size (after the Tumannaya River) river of southern Primorye. The total length of the river is 245 km; over the territory of Primorskii krai it flows at an extent of 191 km. The area of the basin is 16 830 km^2; within Primorskii krai the area is 6820 km^2 (*Resources of Surface Waters...*, 1972). Over the territory of the Russian Federation, Razdol'naya is a river of the plain type. The dominant width of the river is 100–150 m; depth of 0.5 to 5.0 m and at some sites it is to 10 m. Current velocity changes from 0 (between tide and tide-off) to 1.5 m/s (on average, 02–0.3 m/s). The water conditions of the river are characterized by a relatively low spring flood and summer-autumn rain floods; according to average multi-year data, maximum discharges are observed in June and August–September (Fig. 2a). River waters have high turbidity (transparency according to Secci disk is less than 1 m) (Gomoyunov, 1927), especially in the periods of floods. The total solid discharge averages 462 thousand tons; the seasonal course of distribution coincides with changes in water discharge (*State of Marine Ecosystems....*, 2005). Sediments in the lower course are represented by pelites and aleurites. In the warm time of the year, the Razdol'naya River waters warm more rapidly than the waters of Amur Bay (Fig. 2b). The highest water temperature (28–32°C) in the lower course of the river is observed in July or August. The river freezes usually in the first half of November, complete ice melting takes place usually at the end of the first ten day period—beginning of the second ten-day period of April.

The inner estuary is the river section downstream the village of Razdol'noe where there is a slope; tides are observed; the surface water layer is almost fresh; brackish waters are distributed off the bottom. Water salinity of the inner estuary decreases upstream: first rapidly, then more slowly (Fig. 3). Depending on the change in abiotic (firstly, salinity) and biotic (structure and abundance of zooplankton communities, et al.) environmental parameters (Zadonskaya, 1986; Nadtochy et al., 2003; *The State of Marine Ecosystems...*,

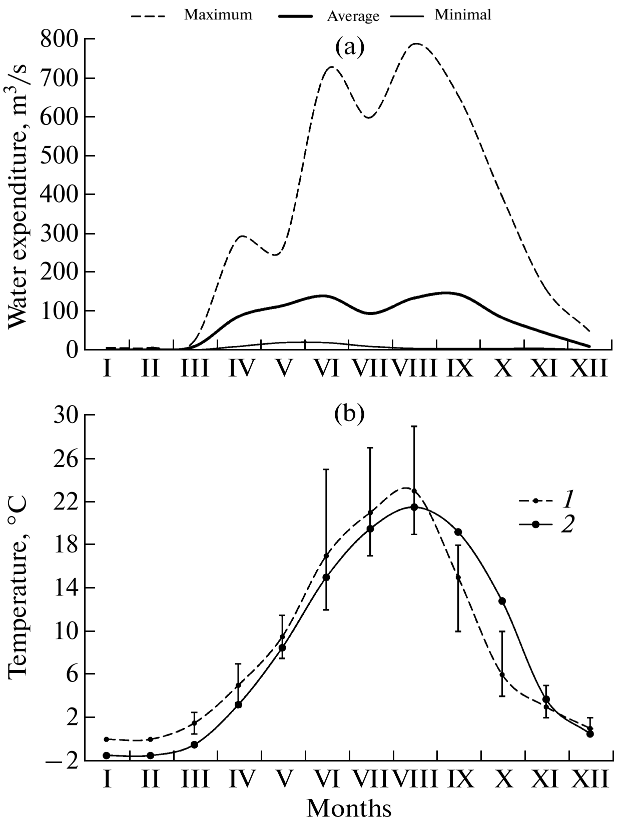

Fig. 2. Average (a) monthly discharges and (b) temperature of surface waters: (a) the Razdol'naya River (*The State of Marine Ecosystems*..., 2005); (b) (*1*) the lower course of the Razdol'naya River (our data), (*2*) coast of Amur Bay (Zuenko, 2002).

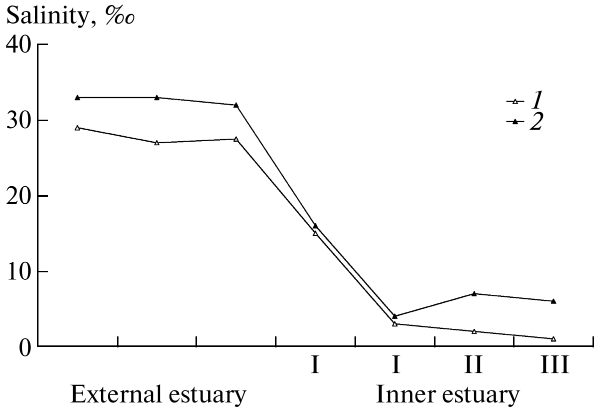

Fig. 3. Distribution of salinity of surface and near-bottom waters in the estuary of the Razdol'naya River along the sea–river direction in the warm period of the year: (*1*) surface waters and (*2*) near-bottom waters (*The State of Marine Ecosystems*..., 2005; with changes).

2005), in the inner estuary of the Razdol'naya River, three sites of information averaging were separated (Figs. 1, 3). In particular, the salinity of surface waters at the low site (I) is the highest, up to 30‰, at the middle site (II) it does not exceed 5–10‰; and at the upper site (III) it is not more than 2–3‰.

Species richness. River conditions in the estuaries are complexly combined with marine conditions; therefore, the composition of their population is distinguished by a high ecological diversity (a red effect manifests itself) (Attrill and Rundle, 2002; Smith et al., 2008). In the estuary of the Razdol'naya River (including the tail part of Amur Bay up to Peschanyi and De Friz peninsulas), no less than 102 fish species from 74 genera and 36 families occur (Shed'ko, 2001; Barabanshchikov and Magomedov, 2002; Shed'ko and Shed'ko, 2003; Kolpakov and Barabanshchikov, 2008). In our collections, 43 fish species from 36 genera of 18 families were recorded (Table 1). The greatest number of species belongs to the families Cyprinidae (16 species) and Gobiidae (6), totaling 22 species (51.2%) (Fig. 4a). The remaining 16 families are represented by 1–2 species. In other words, as in a typical case (Odum, 1986), the estuary ichthyocenosis of the Razdol'naya River consists of different elements and includes: 19 (or 44.2% of the species list) of freshwater, 14 (32.5%) of euryhaline (anadromous, semianadromous, and amphidromous), 6 (14.0%) of local marine species, and 4 (9.3%) of neritic subtropical of the migrant (Fig. 4b, Table 1).

Distribution. In the Razdol'naya River, in the sea–river direction in most cases maximum fish abundance in catches was recorded at the near-estuarine site (I), as well as at sites of the inflow of tributaries of the second order (III) (Fig. 5). In the aquatic medium, maximum "life condensation" is observed in frontal zones (Aizatullin et al., 1984). At mixing of river and marine waters, in the estuaries barriers arise (the so called marginal factors) determined by the change of physicochemical water properties (Lisytsin, 1994) and, firstly, by the transition from hydrocarbonate-calcium to chloride-potassium waters. It was first established that, in the salinity gradient, ecological, physiological, and hydrochemical characteristics change not linearly but with a noticeable abrupt change at a salinity of approximately 5–8‰. At this salinity called "critical" or "chorohaline" zone[1] (Khlebovich, 1974), minimum of marine and freshwater animal species is observed (Remane law of species minimum). Later Aladin (1988) elaborated a concept of multiplicity of zones of barrier salinities separating individual water masses with specific physicochemical properties and, correspondingly, inhabited by specific flora and fauna (Andreeva and Andreev, 2003). Drastic changes in the composition and structure of fish communities in the estuaries, as well as local maximums of their abundance are timed to the boundaries between marine and brackish waters (euhaline barrier) and between brackish and fresh waters (oligohaline barrier) (Bulger et al., 1993; Attrill and Rundle, 2002; Greenwood, 2007).

[1] horeo means I separate (Greek).

Table 1. Composition by weight (above the line, g/m^2) and structure (under the line, %) of net catches of fish in the estuary of the Razdol'naya River

Species	EG	*TL*, mm	Months											
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Clupea pallasii	M	80–370	1.69/2.38	2.59/3.45	62.64/25.78	–	–	–	–	–	–	–	1.93/0.93	12.55/9.19
Konosirus punctatus	NSM	20–120	–	–	–	–	–	–	+/0.05	0.12/4.69	–	3.28/33.84	–	–
Abbottina rivularis	F	25–120	–	–	–	–	0.22/5.49	0.04/0.93	0.27/2.93	0.12/4.59	–	0.16/1.68	+	–
Acanthorhodeus chankaensis	F	20–130	–	–	–	–	0.14/3.40	0.18/4.57	0.72/7.93	0.28/10.99	0.20/4.69	1.83/18.88	–	–
Acanthorhodeus sp.	F	50–130	–	–	–	–	0.06/1.40	0.02/0.61	0.01/0.10	–	0.02/0.50	0.06/0.65	–	–
Carassius gibelio	F	30–220	–	–	–	–	0.01/0.31	0.02/0.51	0.53/5.83	0.01/0.34	0.01/0.41	0.60/6.20	–	–
Culter alburnus	F	50–220	–	–	–	–	0.64/16.03	0.01/0.35	–	0.28/10.80	0.08/2.01	+/0.02	–	–
Gobio macrocephalus	F	30–140	–	–	–	–	0.81/20.33	0.73/18.23	2.08/22.83	0.91/35.38	2.79/66.69	0.39/4.06	+	–
Hemiculter leucisculus	F	50–160	–	–	–	–	+/0.04	0.02/0.40	0.15/1.60	0.05/2.02	–	+/0.02	–	–
Leuciscus waleckii tumensis	F	80–250	–	–	–	–	0.02/0.45	0.08/2.04	0.02/0.20	0.01/0.39	0.02/0.54	–	–	–
Phoxinus sp.	F	40–120	–	–	0.01/+	–	+/0.02	0.03/0.79	–	+/0.05	0.02/0.47	0.02/0.16	–	–
Ph. mantschuricus	F	30–100	–	–	–	–	–	0.01/0.14	0.38/4.18	–	–	0.05/0.55	–	–
Pseudorasbora parva	F	40–110	–	–	–	–	–	0.01/0.11	0.02/0.25	0.02/0.81	0.08/1.80	0.02/0.16	–	–
Rhodeus sericeus	F	20–100	–	–	–	–	0.07/1.78	0.16/4.04	0.15/1.64	0.20/7.94	0.12/2.87	0.16/1.69	–	–

Table 1. (Contd.)

Species	EG	*TL*, mm	Months											
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Sarcocheilichthys czerskii	F	40–120	–	–	–	–	0.10/2.44	0.01/0.30	+/0.04	0.03/1.34	0.03/0.74	0.01/0.13	–	–
Sarcocheilichthys sp.	F	40–120	–	–	–	–	–	–	–	+/0.02	–	–	–	–
Tribolodon spp.*	ASA	40–150	–	–	7.79/3.21	72.08/19.30	0.14/3.54	0.17/4.31	0.55/6.10	0.09/3.61	0.19/4.45	0.66/6.83	1.75/0.85	71.61/52.45
Cobitis lutheri	F	40–120	–	–	–	–	+/0.08	+/0.05	0.06/0.68	+/0.08	0.13/3.20	–	–	–
Barbatula toni	F	90–100	–	–	–	–	–	–	–	–	–	+/0.04	–	–
Silurus asotus	F	50–220	–	–	–	–	–	–	–	–	+/0.04	–	–	–
Hypomesus nipponensis	ASA	40–120	69.44/97.62	72.42/96.55	164.19/67.57	294.17/78.76	0.03/0.71	0.03/0.86	0.24/2.62	0.26/9.98	+/0.04	0.86/8.82	190.33/92.31	25.19/18.45
Osmerus dentex	ASA	80–140	–	–	0.02/0.01	–	–	–	–	–	–	0.02/0.20	0.12/0.06	0.04/0.03
Salangichthys microdon	NSM	60–100	–	–	–	–	0.04/1.01	+/0.04	+/0.01	+/0.06	+/0.01	+	–	–
Oncorhynchus masou	ASA	130	–	–	–	–	0.01/0.12	–	–	–	–	–	–	–
Eleginus gracilis	M	80–140	–	–	1.37/0.56	–	–	–	–	–	–	0.07/0.68	3.02/1.46	1.73/1.27
Hyporhamphus sajori	NSM	90–150	–	–	–	–	–	–	–	+/0.14	0.02/0.35	–	–	–
Gasterosteus sp.	ASA	50–80	–	–	–	–	0.10/2.44	0.25/6.21	–	–	–	–	–	–
Pungitius sinensis	ASA	40–70	–	–	–	–	+/0.03	0.01/0.13	0.01/0.13	+/0.09	0.02/0.50	0.07/0.69	0.04/0.02	–
Syngnathus schlegeli	NSM	100–200	–	–	–	–	–	+/0.01	–	–	–	–	–	–

Table 1. (Contd.)

Species	EG	*TL*, mm	Months											
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Sebastes schlegelii	M	80–140	–	–	–	–	–	–	–	–	–	–	0.14/0.07	0.04/0.03
Liza haematocheila	ASA	40–160	–	–	6.33/2.60	6.00/1.61	1.42/35.64	2.12/52.90	2.21/24.26	0.04/1.68	–	1.16/11.92	8.65/4.20	25.36/18.58
Pholis nebulosa	M	80–150	–	–	–	–	–	0.01/0.25	–	–	–	–	–	–
Perccottus glenii	F	25–180	–	–	–	–	–	+/0.07	1.55/17.02	–	–	0.12/1.20	–	–
Acanthogobius lactipes	ASA	30–100	–	–	–	–	0.10/2.50	0.01/0.12	+/0.02	+/0.13	0.03/0.71	+/0.03	–	–
A. flavimanus	ASA	30–200	–	–	–	–	+/0.02	0.03/0.69	0.11/1.20	0.10/3.75	0.03/0.83	0.08/0.79	–	–
Gymnogobius taranetzi	ASA	30–80	–	–	–	–	0.01/0.17	+/0.06	0.01/0.11	+/0.08	0.11/2.74	0.05/0.48	–	–
G. urotaenia	ASA	50–120	–	–	–	–	0.06/1.56	0.02/0.41	0.02/0.19	0.02/0.64	0.02/0.36	0.02/0.22	–	–
Tridentiger bifasciatus	ASA	30–75	–	–	–	–	0.01/0.21	+/0.03	–	+/0.03	–	+/0.02	–	–
T. brevispinis	ASA	30–95	–	–	–	–	0.01/0.28	–	0.01/0.09	+/0.12	0.25/6.06	0.01/0.06	–	–
Channa argus	F	120–200	–	–	–	–	–	–	–	0.01/0.23	–	–	–	–
Liopsetta pinnifasciata	M	40–150	–	–	0.62/0.25	1.25/0.33	–	0.03/0.84	+/0.01	–	–	–	0.21/0.10	+
Platichthys stellatus	M	40–180	–	–	0.01/0.01	–	–	–	–	–	–	–	–	0.01/0.01
Total	–	–	71.14	75.02	242.98	373.5	3.98	4.00	9.09	2.57	4.18	9.70	206.19	136.54
Number of seinings	–	–	6	11	35	4	21	34	78	29	17	30	27	10

Note: EG is ecological groups, M is local marine species, NSM is neritic subtropical migrants, F is freshwater species, and ASA is anadromous, semianadromous, and amphidromous species. TL is total body length from the end of the snout to the end of spiny fin. * is category of *Tribolodon* spp. including two species—*T. brandtii* and *T.hakonensis*. "+", <0.01 g/m^2 (or %), "–" is absence in catches. The order of fish families in the table is adopted in correspondence with the Eschmeyer system (2003); within the family, different species are arranged in the alphabetical order.

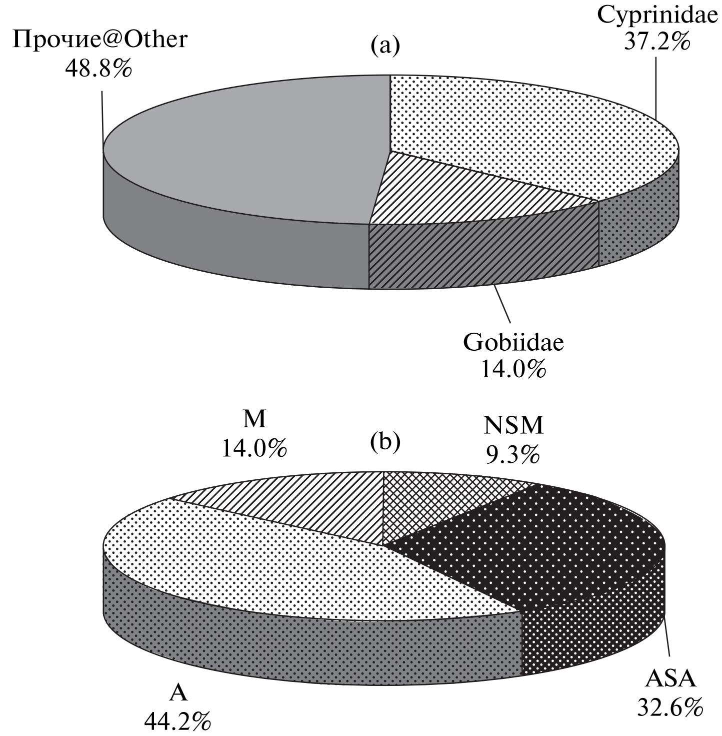

Fig. 4. (a) Taxonomic and (b) ecological structure of the estuary of the Razdol'naya River ($n = 43$). Ecological groups: M is local marine species, NSM is neritic subtropical migrants, F is freshwater species, and ASA is anadromous, semianadromous, and amphidromous species.

The aforementioned maximums of fish abundance in the estuary of the Razdol'naya River are timed precisely to such zones (Figs. 1, 2, 3). Besides, an increase in fish biomass in the area of marginal filters is apparently determined by the high abundance and accessibility of food—plankton here (Barabanshchikov, 2005), benthos (Nadtochii et al., 2008), and detritus (Khodorenko et al., 2008; unpublished data by Yu.A. Galysheva, DVGU[2] (Dolganova et al., 2008). Thus, we can assume that fish distribution in the estuary of the Razdol'naya River is determined by the thermohaline conditions of waters and the trophic factor. The same conclusion was made by Zemnukhov (2008) who studied specific features of fish distribution in Bay Piltun (northeastern Sakhalin).

Using cluster analysis, we distinguished two groups of fish differing in the type of distribution in the summer period (July–August) (let us call them conventionally "river" (F) and "marine" (M), and each of them, in turn, includes two subgroups of species (Fig. 6).

The first subgroup of river group (Fa) combines fish tending in their distribution to the upper part of the studied site III (Fig. 7); these are stenohaline freshwater species (spined loach *Cobitis lutheri*, lake minnow *Phoxinus mantschuricus*, goldfish *Carassius gibelio*, lookup *Culter alburnus*, Amur catfish *Silurus asotus*, Amur sleeper *Percottus glenii*, stone moroco *Pseudorasbora parva*, and minnow *Phoxinus* sp.) and oligohaline amphidromous threetooth goby *Tridentiger brevispinus*.

Representatives of the second subgroup (Fb) are relatively numerous at sites II and III; i.e., they dwell in a wider range of salinity (euryhaline river species). This subgroup also includes amphidromous Far Eastern gobies *Gymnogobius urotaenia* and *G. taranetzi*, semianadromous river Japanese smelt *Hypomesua nipponensis*, and freshwater euryhaline species (*Abbotina rivularis*, bitterlings *Acanthorhodeus chankaensis* and *A.* sp., Chanka bitterlings, spiny bitterling *Rhodeus sericeus*, ide *Leuciscus waleckii tumensis*, Korean sawbelly *Hemiculter leuciscus*, and gudgeon *Sarcocheilichthys czerskii*).

Fish included in the "marine" group (M) are most abundant in the lower part of the studied site (Fig. 7). The first subgroup (Ma) consists of euryhaline semianadromous haarder *Liza haimatocheila* and yellowfin goby *Acanthogobius flaminus*, freshwater gudgeon *Gobio macrocephalus* and Chinese stickleback *Pungittius sinensis* and subtropical neritic gizzard shad *Konosirus punctatus* that are most numerous at sites II and I (Figs. 1, 7).

[2] In the food of fish from the estuary of the Razdol'naya River, detritus and animal detritophages—polychaetes, gammarids, and decapods dominate.

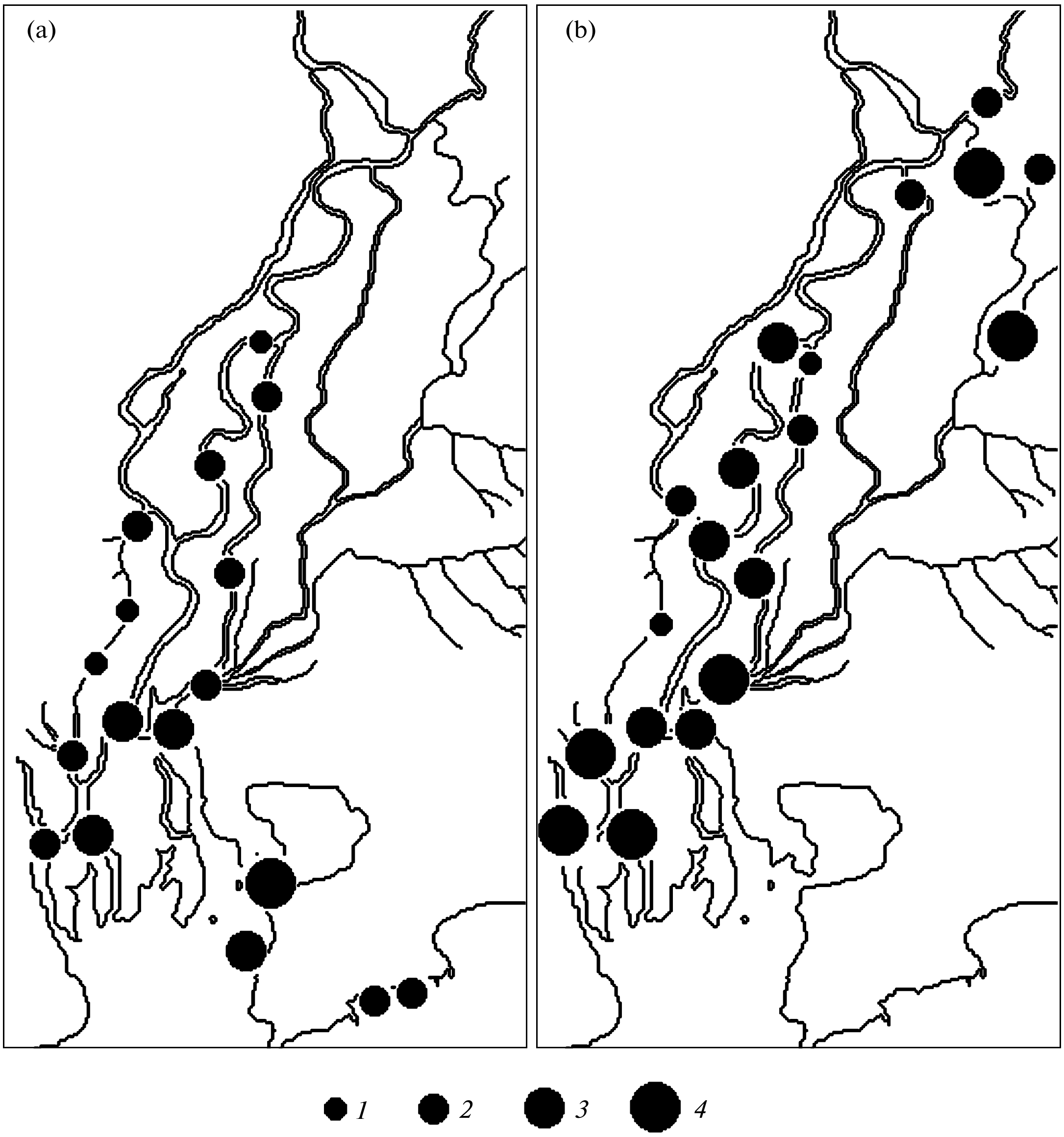

Fig. 5. Fish distribution in the basin of the Razdol'naya River in (a) June and (b) July of 2007. Designations (g/m^2): *1* is 0–1, *2* is 1–10, *3* is 10–20, and *4* is greater than 20.

Finally, the last group (Mb) includes species most abundant at site I, i.e., dwelling at relatively high salinity values. These are euryhaline amphidromous *Acanthogobius lactipes* and goby *Tridentiger bifasciatus*, semianadromous Far Eastern rudds *Tribolodon* spp. and Japanese three-spined stickleback *Gasterosteus* sp., subtropical neritic Japanese halfbeak *Hyporhamphus sajori* and pipefish *Sygnathus schlegeli*, marine tidepool gunnel *Pholis nebulosa*, and flounder *Liopsetta pinnifasciata*.

Thus, in the summer period, the structure of ichthyocenoses changes along the salinity gradient in correspondence with the biotopic preferences of different species. Their integral characteristics also differ (Fig. 8). At the upper site, the proportion of freshwater fish species is maximum (89.8%), fish abundance (4.1 g/cm^2) and species diversity ($S_{\lambda'}$ = 1/23) is minimal, and species richness is high (31 species). At the middle site, the bulk of catches consists of freshwater (52.0%) and semianadromous (44.1%) species, diversity ($S_{\lambda'}$ = 2.15) and species richness (52 species) are maximum, and biomass increases to 5.3 g/m^2. At the lower site, semianadromous (64.8%) and amphidromous (8.6%) species dominate; the proportion of marine species increases to 1.6%, and the proportion of freshwater species decreases to minimum (24.2%). Species richness decreases to minimum (22), diversity also slightly decreases ($S_{\lambda'}$ = 2.06), and biomass reaches maximum value (8.0 g/m^2).

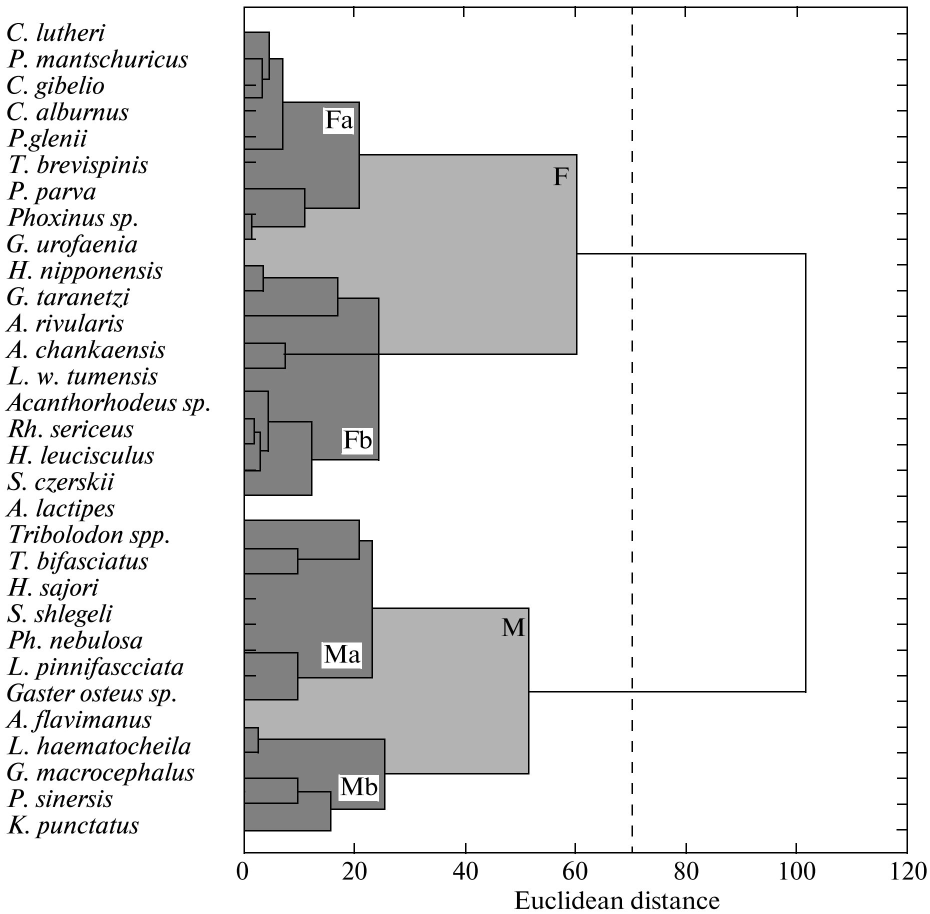

Fig. 6. Dendrogram of similarity of distribution of the most common fish species in the Razdol'naya River in the sea-river direction (June–August). Dotted line is significance level. Designations of groups: F is river, M is marine, Fa is species tending in their distribution to site III (see Fig. 1), Fb is species relatively numerous at sites II and III, Ma is species most numerous at sites II and I, and Mb is species most abundant at site I.

Seasonal changes. The seasonal succession of estuary ichthyocenosis of the Razdol'naya River includes two periods: warm (May–October) and cold (November–April). The warm period is characterized by a small biomass (4–10 g/m^2) and maximum species richness (22–29 species) (Fig. 9). In the cold period, species richness is minimal (2–12 species), and biomass, on the contrary, is very high (on average, 71–374 g/m^2); at some sites of wintering depressions it is up to 2 kg/m^2). Such biomass level in wintering depressions can be provided only on condition that fish here do not feed at all or their feeding activity is minimal. In the periods of ice freezing and melting, species richness and biomass change unidirectionally (Fig. 9); at this time, local maximums of both characteristics were recorded.

It is known that the seasonal course of changes in fish communities in the estuaries, besides the rhythm of biological seasons and changes in water temperature, are considerably determined by the annual conditions of discharge, as well as by water turbidity (Whitfield and Harrison, 1993). To determine the degree of dependence of species richness and fish abundance on several environmental factors, Spearman's rank correlation coefficients were calculated (Table 2). As a result it became apparent that (1) at an increase in water discharge, the volume of solid discharge, and water temperature, fish biomass in catches reliably decreases; (2) species richness increases in this case. At an increase in water discharge and volume of solid discharge in the summer period, the scale of penetration of high-saline waters to the estuary decreases and water turbidity increases (*The State of Marine Ecosystems*...,2005). Correspondingly, the scale of the presence of euryhaline species forming high biomasses decreases in the estuary. Wintering of semianadromous fish in the estuary proceeds under conditions of an increase in water salinity at the expense of a decrease in the volume of freshwater discharge (*The State of Marine Ecosystems*..., 2005).

From January to February, only two pelagic species—Japanese smelt (semianadromous) and Pacific herring *Clupea pallasii* (local marine)—were recorded (Table 1, Fig. 10a). The remaining species are low

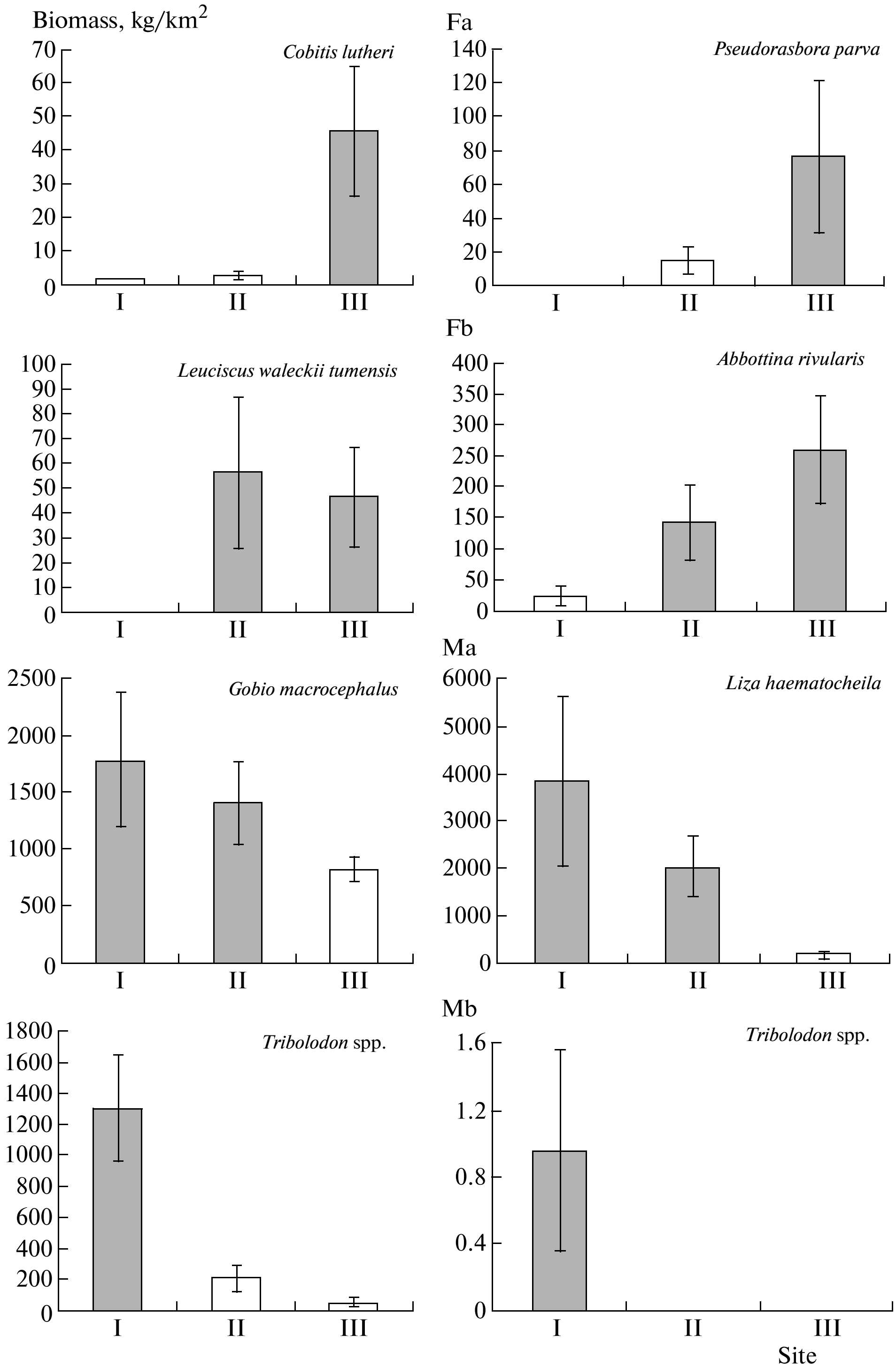

Fig. 7. Change in density concentration (kg/km^2) of some fish species in the sea–river direction. Vertical lines are error of the average. Designations of groups are the same as in Fig. 6.

active and lie in wintering depressions in the main channel or in accessory water bodies. From November to December (freezing) and March–April (ice run), in the river a high proportion of semianadromous (rudd, smelt, and haarder) and marine (Pacific herring, navaga *Eleginus gracilis*, perch *Sebastes schlegeli*, and flounders *Platichthys stellatus* and *Liopsetta pinnifasciata*) fish species is observed. The summer aspect of community is characterized by the domination of cyprinids and other freshwater species, comparatively low

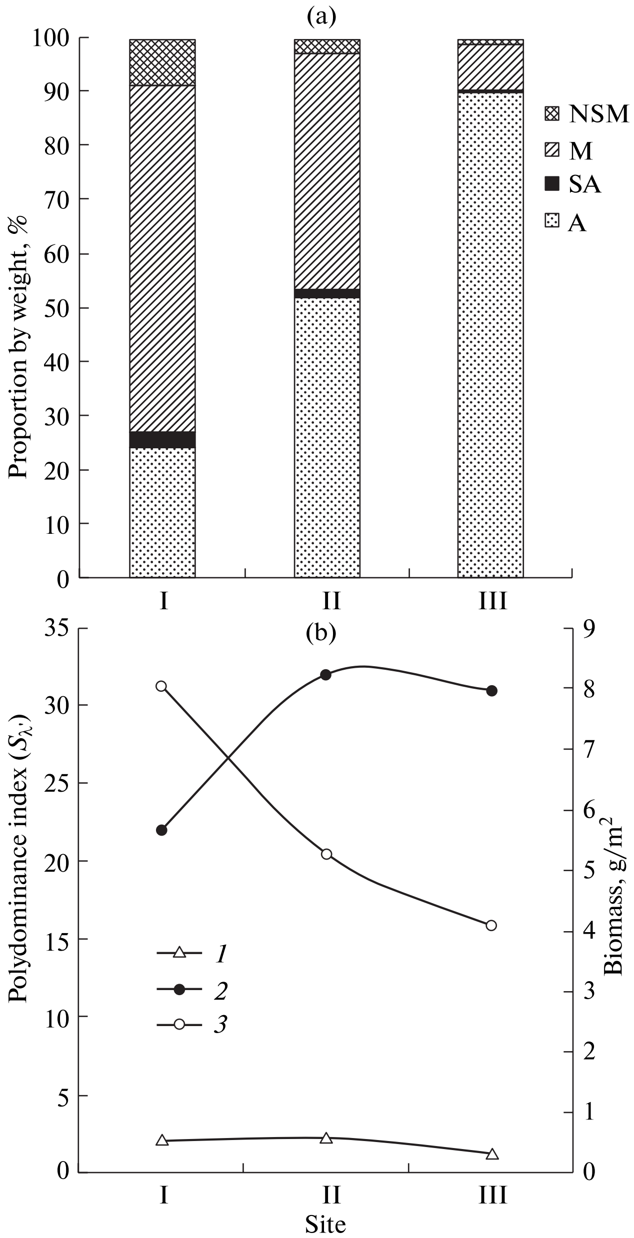

Fig. 8. Longitudinal change of the (a) structure of ichthyocenoses and their (b) integral characteristics. (*1*) polydominance index ($S_{\lambda'}$), (*2*) species richness (S), and (*3*) fish biomass, g/m^2. The remaining designations are the same as in Fig. 4.

proportion of semianadromous fish (haarder, rudd), and appearance of subtropical migrants (gizzard shad). From summer to autumn, the proportion of semianadromous and estuary marine species increases, and the proportion of freshwater species decreases. In the space of two main components with respect to the structure of catches, the same two periods are distinguished: during May–October, as was already mentioned, freshwater and southern neretic species dominate; in November–April, nonanadromous and local marine species prevail (Fig. 10b).

Such dynamics of species composition is determined by specific features of life cycles of different fish, in particular, by their seasonal migrations. In summer, rudds and Japanese smelt after spawning migrate for feeding to coastal waters; haarder migrates there for reproduction; freshwater species (gudgeons, goldfish, ide *Leuciscus waleckii*, et al.) at this time after spawning come out of the accessory system and move to the main channel and descend to the estuary zone for feeding. In autumn, semianadromous species (juveniles of rudds and haarder, Japanese smelt) ascend from the sea to the upper part of the estuary for

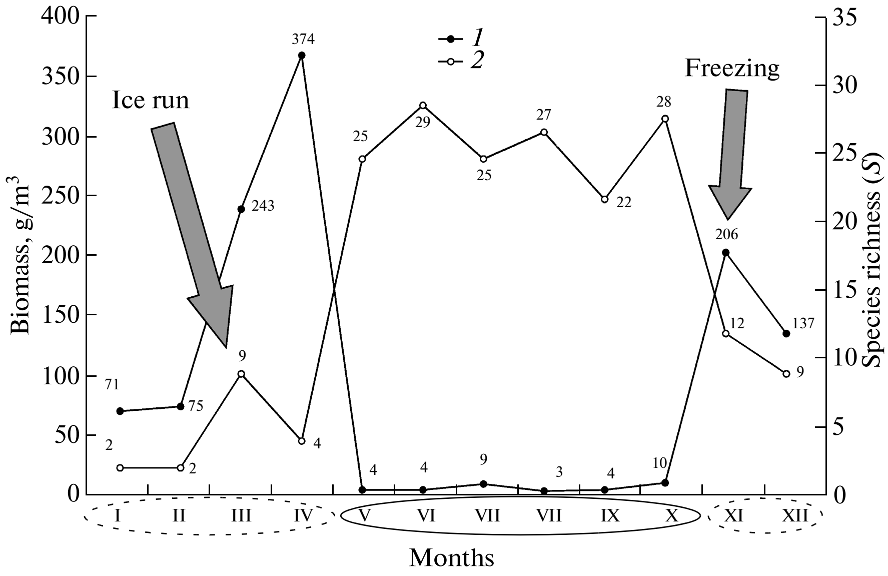

Fig. 9. Seasonal changes in the (*1*) biomass and (*2*) species richness of ichthyocenosis in the estuary of the Razdol'naya River (according to data of net catches). Arabic figures at plots show the values of biomass and species richness in each month.

wintering in depressions in the main channel and large tributaries; freshwater fish for wintering move from the main channel to the accessory system; marine species (herring, navaga, flounders) enter the estuary for feeding and wintering (Kolpakov, 2008a, 2008b). In spring a reverse process occurs.

Note that the same regularities are true for large fish. According to data of net catches (mesh of 20–70 cm) (Kolpakov and Barabanshchikov, 2008), the number of species increases in the warm time of the year (June–September). In catches, freshwater fish (Amur carp *Cyprinus rubrofuscus*, goldfish, ide *Leuciscus waleckii*, and Amur catfish *Silurus asotus*), warm-water southern migrants (gizzard shad, striped mullet *Mugil cephalus*, Japanese anchovy *Engraulis japonicus*, Pacific needlefish *Strongylura anastomella*, and *Takifugu xanthopterus*, and Pacific salmon (masu salmon *Oncorhynchus masou*, and chum salmon *O. keta*) dominate. From October to May, the bulk of catches consists of rudd and haarder, as well as of Pacific herring, navaga, *Myoxocephalus jaok*, and flounders *Liopsetta pinnifasciata* and *Platichthys stellatus*.

Table 2. Matrix of correlations (lg) of fish biomass and their richness with seasonal dynamics of water discharge, solid discharge (average-long-term data), and water temperature in the lower course of the Razdol'naya River

Index	Average discharge, m^3/s	Biomass, g/m^2	Number of species	Temperature, °C	Solid discharge, thousands tons
Average discharge, m^3/s	1	**–0.70** / 0.0120	**0.70** / 0.0050	**0.91** / 0.0001	**0.85** / 0.0004
Biomass, g/m^2		1	**–0.69** / 0.0130	**–0.72** / 0.0090	**–0.65** / 0.0200
Number of species			1	**0.83** / 0.0010	0.52 / 0.0770
Temperature, °C				1	**0.82** / 0.0010
Solid discharge, thousands tons					1

Note: Above the line is Spearman correlation coefficient values (statistically significant are bold-typed) and below the line is probability (values are significant at $p < 0.05$).

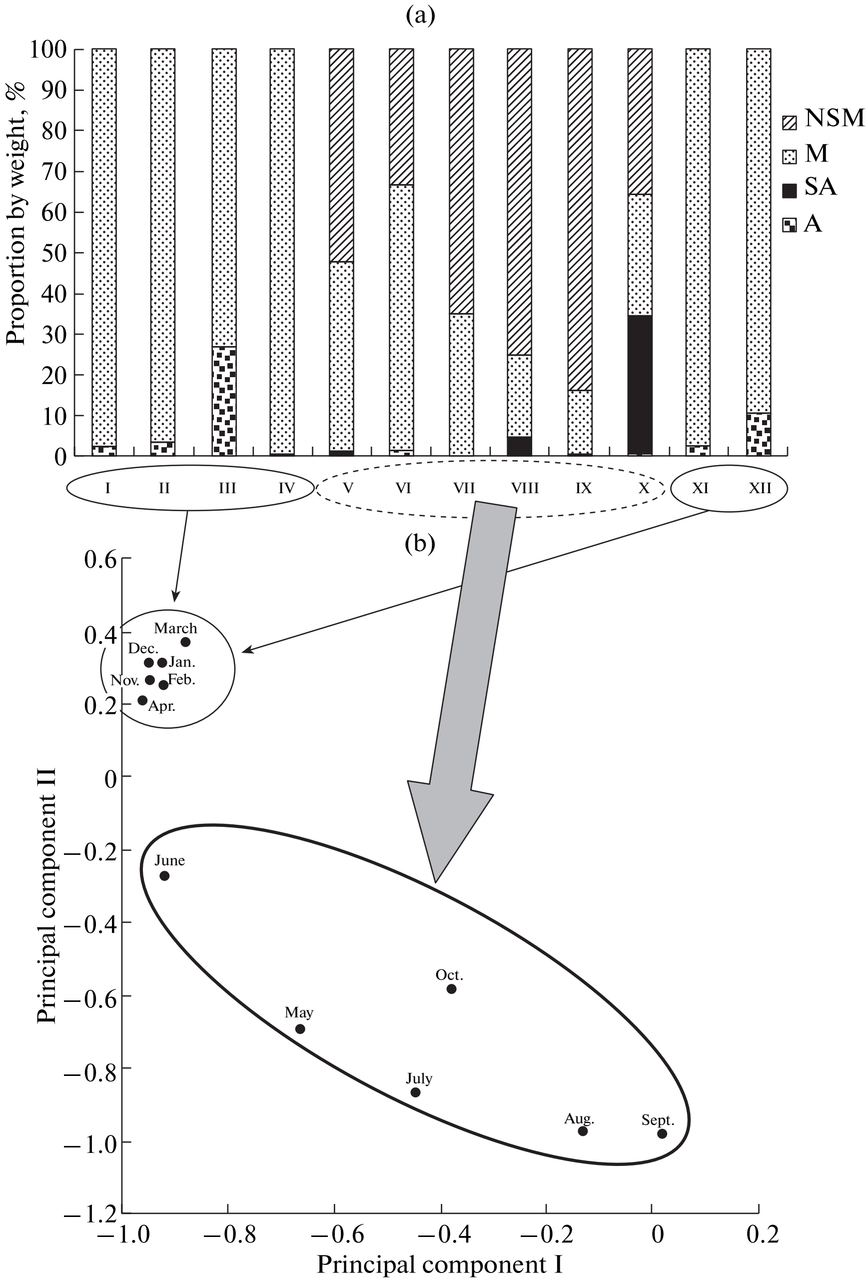

Fig. 10. (a) Seasonal changes in the ratio of fish from different ecological groups in net catches and (b) distribution of different months (by the structure of catches) in the space of principal components. Designations are the same as in Fig. 4.

CONCLUSIONS

The distribution of fish in the estuary of the Razdol'naya River is determined by both thermohaline conditions of waters and by a trophic factor. Along the salinity gradient, the structure of ichthyocenoses and their integral characteristics change. At the upper site, the proportion of freshwater stenohaline fish species is maximum, and fish abundance is minimal. At the middle site, the bulk of catches is made by euryhaline and semianadromous species (almost in an equal ratio). At the low (near-estuarine) site, semianadromous and amphidromous species dominate; the proportion of freshwater species decreases to minimum; fish biomass is the highest here. Thus, drastic changes in the structure of ichthyocenoses and an increase in fish biomass are related to zones of barrier specific features where nonlinear changes of physico-chemical water properties occur, and increased biomasses of food animals are formed.

The seasonal succession of estuary ichthyocenoses of the Razdol'naya River includes two periods: warm (May–October) and cold (November–April). The warm period is characterized by a small biomass and maximum species richness against the background of an increase in water discharge, turbidity, and temperature and a decrease in the volume of high-saline waters in the estuary. In catches, cyprinids and other freshwater species dominate; the proportion of semianadromous fish (haarder and rudds) decreases, but subtropical migrants (gizzard shad) appear. In the estuary, the feeding of euryhaline freshwater species and the feeding and spawning of marine euryhaline (warm-water) species occur. In the cold period of the year, species richness is minimal, and salinity, on the contrary, is maximum. At this time in the estuary, pre- and postwintering migrations, as well as wintering of semianadromous and freshwater species and feeding of marine species, occur.

On the whole, we conclude that the spatio-temporal structure of ichthyocenoses in the estuary of the Razdol'naya River are formed under the impact of a set of abiotic (thermohaline conditions, discherge volume) and biotic (trophical relations, life cycles of fish) factors.

ACKNOWLEDGMENTS

We are grateful to M.M. Faizullin and P.P. Pilipenko (TINRO-Center) for great help in material collecting.

REFERENCES

1. T. A. Aizatullin, V. L. Lebedev, and K. M. Khailov, *Ocean: Fronts, Dispersion, and Life* (Gidrometeoizdat, Leningrad, 1984) [in Russian].
2. N. V. Aladin, "Concept of Relativity and Multiplicity of Zones of Barrier Salinities," Zh. Obshch. Biol. **49** (6), 825–833 (1988).
3. S. I. Andreeva and N. I. Andreev, *Evolutionary Transformations of Bivalves in the Aral Sea under Conditions of an Ecological Crisis* (Omsk. Gos. Ped. Univ., Omsk, 2003) [in Russian].
4. M. J. Attrill and S. D. Rundle, "Ecotone or Ecocline: Ecological Boundaries in Estuaries," Estuar. Coast. Shelf Sci. **55**, 929–936 (2002).
5. E. I. Barabanshchikov, "Zooplankton and Marginal Filters of Estuarine Systems of Primorye," in *Abstr. PICES. XIV Ann. Meet. Vladivostok, Russia, September, 29, 2005* (2005), p. 169.
6. E. I. Barabanshchikov and R. A. Magomedov, "Composition and Some Features of Biology in Fish of the Estuary Zone of Rivers of Southern Primorye," Izv. Tikhookean. Nauchno-Issled. Rybokhoz. Tsentra **131**, 179–200 (2002).
7. A. J. Bulger, B. P. Hayden, M. E. Monaco, et al., "Biologically-Based Estuarine Salinity Zones Derived from a Multivariate Analysis," Estuaries **16**, 311–322 (1993).
8. I. V. Burkovskii, A. P. Stolyarov, and M. Yu. Kolobov, "Spatial Organization and Functioning of the Marine (Estuary) Coastal Ecosystem," Usp. Sovrem. Biol. **122** (4), 316–325 (2002).
9. N. T. Dolganova, N. V. Kolpakov, and V. I. Chuchukalo, "Feeding Interactions and Foraging of Juvenile Fish and Shrimp in the Estuaries of Peter the Great Bay in the Summer-Fall Period," Russ. J. Mar. Biol. **34** (7), 482–489 (2008).
10. W. Eschmeyer, Annotated Checklists of Fishes. *http://www.calacademy.org/research/ichthyology/annotated/AnnChkPhyl.php (2003)*.
11. A. Franco, M. Elliott, P. Franzoi, and P. Torricelli, "Life Strategies of Fishes in European Estuaries: The Functional Guild Approach," Mar. Ecol. Progr. Ser. **354**, 219–228 (2008).
12. K. A. Gomoyunov, "Hydrological Survey of Amur Bay and the Suifun River," in *Productive Potential of Far East* (Vladivostok, 1927), Issue 2, p. 73.
13. M. F. D. Greenwood, "Nekton Community Change Along Estuarine Salinity Gradients: Can Salinity Zones Be Defined?," Estuaries Coasts **30** (3), 537–542 (2007).
14. V. N. Ivankov, V. V. Andreeva, N. V. Tyapkina, et al., *Biology and Food Resources of Pacific Salmon in the Early Marine Period of Life* (DVGU, Vladivostok, 1999) [in Russian].
15. A. I. Kafanov, V. S. Labai, and N. V. Pecheneva, *Biota and Communities of Macrobenthos of Lagoons of Northeastern Sakhalin* (SakhNIRO, Yuzhno-Sakhalinsk, 2003) [in Russian].
16. V. I. Karpenko, *Early Marine Period of Life of Pacific Salmon* (VNIRO, Moscow, 1998) [in Russian].
17. B. N. Kazanskii, "Fish Resources of Inland Water Bodies of Far East and Ways for Their Reproduction," in *Fauna and Perspectives of Fish-Cultural Use of Continental Water Bodies of Far East*, Uch. Zap. Dal'nevost. Gos. Univ. **15** (3), 5–18 (1971).
18. V. V. Khlebovich, *Critical Salinity of Biological Processes* (Nauka, Leningrad, 1974) [in Russian].
19. N. D. Khodorenko, T. I. Volkova, and P. Ya. Tishchenko, "Humic Substances and Macrocomposition of Bottom Sediments in the Lower Course of the Razdol'naya River in the Northern Part of Amur Bay (Sea of Japan)," in *Modern State and Tendencies of Environmental Change in Peter the Great Bay of the Sea of Japan* (Geos, Moscow, 2008), p. 229.
20. N. V. Kolpakov, "New Data on the Composition and Distribution of Fish in Some Estuaries of Southern Primorye in Summer–Fall of 2005 and 2006. 1. Razdol'naya River," Izv. Tikhookean. Nauchno-Issled. Rybokhoz. Tsentra **153**, 153–167 (2008a).
21. N. V. Kolpakov, "New Data on the Composition and Distribution of Fish in Some Estuaries of Southern Primorye in Summer–Fall of 2005 and 2006. 2. Small Water Bodies," Izv. Tikhookean. Nauchno-Issled. Rybokhoz. Tsentra **153**, 168–181 (2008b).
22. N. V. Kolpakov and E. I. Barabanshchikov, "Species Composition and Seasonal Dynamics of Ichthyofauna of Razdolnaya River's Estuary," in *Aquatic Biodiversity and Sustainable Development of Estuaries. Proc. Int. Symp. Aquatic Biodiversity Conservation and Environmental Restoration of Estuarine and Coastal Areas. Octo-*

ber 2006, Shanghai (Shanghai Sci. & Techn. Publ., Shanghai, 2008), p. 92.
23. A. P. Lisitsyn, "Marginal Filters of Oceans," Okeanologiya **34** (5), 735–747 (1994).
.24. V. V. Maksimenkov, Doctoral Dissertation in Biology (TINRO-Tsentr, Vladivostok, 2002) [in Russian].
25. S. Mathieson, A. Cattrijsse, M. J. Costa, et al., "Fish Assemblages of European Tidal Marshes: A Comparison Based on Species, Families and Functional Guilds," Mar. Ecol. Progr. Ser. **204**, 225–242 (2000)
26. V. A. Nadtochy, R. G. Bezrukov, and L. L. Budnikova, "Macrozoobenthos of Some Estuary Systems of Southern Primorye," in *Marine Coastal Ecosystems. Algae, Invertebrates, and Products of Their Processing, Abstracts of Papers of III International Conference* (TINRO-Tsentr, Vladivostok, 2008), p. 115.
27. V. V. Nadtochy, Y. I. Zuenko, and E. I. Barabanshchikov, "River-Sea Change of Zooplankton Species Composition: A Case of Amur Bay (Japan/East Sea)," Abstr. PICES, 12th Ann. Meet. Seoul, R. Korea, 2003 (2003), p. 33.
28. E. Odum, *Basic Ecology* (Saunders, Philadelphia, 1983).
29. A. A. Ogorodnikova, *The Ecologo-Economic Assessment of the Impact of Coastal Sources of Pollution on Environment and Bioresources of Peter the Great Bay* (TINRO-Tsentr, Vladivostok, 2001) [in Russian].
30. Yu. A. Pesenko, *Principles and Methods of Quantitative Analysis in Faunistic Studies* (Nauka, Moscow, 1982) [in Russian].
31. *Resources of Surface Waters of the USSR* (Gidrometeoizdat, Leningrad, 1972), Vol. 18, Issue 3, p. 268 [in Russian].
32. S. V. Shed'ko, "A List of Cyclostomata and Fish of the Coast of Primorskii Krai," in *Lectures in Memory of V.Ya. Levanidov* (Dal'nauka, Vladivostok, 2001), Issue 1, p. 229.
33. S. V. Shed'ko and M. B. Shed'ko, "New Data on Freshwater Ichthyofauna of the South of Far East of Russia," in *Lectures in Memory of V.Ya. Levanidov* (Dal'nauka, Vladivostok, 2003), Issue 2, p. 319.
34. T. M. Smith, J. S. Hindell, G. P. Jenkins, and R. M. Connolly, "Edge Effects on Fish Associated with Seagrass and Sand Patches," Mar. Ecol. Progr. Ser. **359**, 203–213 (2008).
35. *The State of Marine Ecosystems Subjected to the Impact of the River Discharge* (Dal'nauka, Vladivostok, 2005), p. 261 [in Russian].
36. T. A. Visintainer, S. M. Bollens, and Ch. Simenstad, "Community Composition and Diet of Fishes As a Function of Tidal Channel Geomorphology," Mar. Ecol. Progr. Ser. **321**, 227–243 (2006).
37. A. K. Whitfield, "Ichthyofaunal Assemblages in Estuaries: A South African Case Study," Rev. Fish. Biol. Fish **9**, 151–186 (1999).
38. A. K. Whitfield and T. D. Harrison, "River Flow and Fish Abundance in a South African Estuary," J. Fish. Biol. **62**, 1467–1472 (2003).
39. T. A. Zadonskaya, "Spatial Variation of the Structure of Plankton Community in Estuaries," in *Conservation of the Natural Environment of Seas and River Estuaries,* in *Abstracts of Papers of the All-Union Conference* (Vladivostok, 1986), Vol. 2, p. 30.
40. V. V. Zemnukhov, Candidate's Dissertation in Biology (IBM DVO RAS, Vladivostok, 2008).
41. Yu. I. Zuenko, "Seasonal and Interannual Variation of Water Temperature in the Northwestern Part of the Sea of Japan," Izv. Tikhookean. Nauchno-Issled. Rybokhoz. Tsentra **131**, 3–21 (2002).