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Marine Micropaleontology 63 (2007) 111–142
MARINE MICROPALEONTOLOGY
www.elsevier.com/locate/marmicro

Comparison study of the modern ostracod associations in the Kara and Laptev seas: Ecological aspects

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Received 18 April 2006; received in revised form 12 October 2006; accepted 17 October 2006

Abstract

Recent ostracod assemblages were investigated from coretop sediment samples collected in the eastern Kara Sea from water depths down to 300 m. A total of 45 species were identified, 27 of them were reported for the Kara Sea for the first time. The Kara Sea data were compared with our results on the distribution of ostracods in the eastern Laptev Sea. The spatial distribution of recent taxa and the ecological groupings demonstrate a clear relation to dominant environmental factors which range from estuarine to full-marine conditions. Four assemblages related to average summer bottom water salinities were established: (1) a freshwater assemblage from the inner estuaries of the Ob' and Yenisei rivers with salinities less than 2 and from thermokarst lagoons of the southern Laptev Sea coast with strong salinization in winter; (2) a brackishwater assemblage of the outer estuaries of the Ob' and Yenisei rivers with salinities up to 26; (3) a mixed euryhaline–marine assemblage dominated by euryhaline species *Paracyprideis pseudopunctillata* and *Heterocyprideis sorbyana* from the inner shelf river-affected zone of the Kara and Laptev seas, where salinities range between 26 and 32; (4) a taxonomically diverse marine assemblage dominated by shallow-water marine taxa from the northern parts of the Kara and Laptev shelves and upper continental slope with stable bottom environments and a salinity higher than 32. Abundant euryhaline species found at greater water depths are identified as part of an ice-rafted assemblage. They are possibly entrained into the newly formed fast ice during autumn storms and freeze-up period and then transported to the distal open-sea areas during summer.

Keywords: Ostracoda; Kara Sea; Laptev Sea; Ecology; River runoff; Bottom water salinity

1. Introduction

Ostracods represent an important group of meiobenthic organisms inhabiting a great range of aquatic environments from freshwater pools to marine deep-sea basins. Ostracods possess a calcareous carapace which is usually well-preserved in sediments after burial. Their wide distribution, high abundance in sediments and occurrence in certain environments make ostracods a valuable tool for paleoreconstructions in Eurasian Arctic shelf seas subjected to strong riverine influence. The Eurasian river runoff determines the hydrological, biological and sea-ice conditions, as well as sedimentary

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doi:10.1016/j.marmicro.2006.10.003

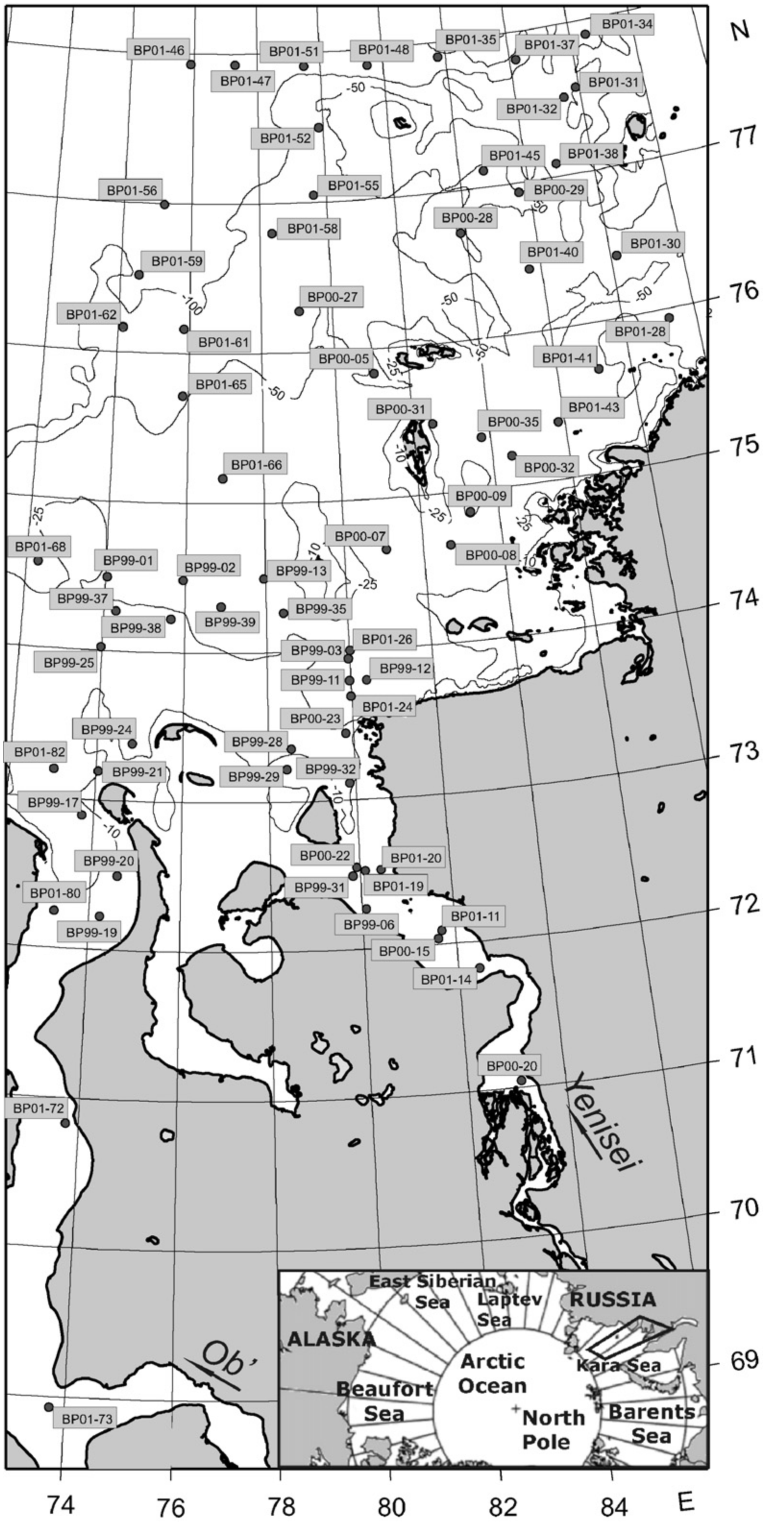

Fig. 1. Sampling locations in the eastern Kara Sea.

environments on the shelves adjacent to river mouths, and it also influences the thermohaline circulation in the Arctic Ocean and North Atlantic, thus affecting the northern high-latitudinal climates (Aagard and Carmack, 1994; Bauch et al., 2000). The Kara and Laptev seas experience a very high riverine influence due to the Ob', Yenisei and Lena rivers, the three largest rivers emptying in the Arctic Ocean. Studies of the distribution of recent ostracods in these seas will give a new insight into the ecology of species, especially, in relation to salinity/river runoff influence, and provide a reliable basis for reconstructing past environmental changes.

In the scope of the Russian–German cooperative research project "Laptev Sea System" we have started investigating recent (found in the uppermost 2 cm of boxcore sediments, not necessarily living) and fossil ostracods from the Laptev Sea collected during TRANSDRIFT V expedition in 1998 (Stepanova et al., 2003, 2004; Stepanova, 2006; Taldenkova et al., 2005). Due to these publications and that of Schornikov (2004), this sea now is one of the best studied Arctic seas in terms of ostracods. In these works both taxonomy and ecology were subject to detailed investigation, and most of identified species were illustrated. At the same time, data on the Kara Sea ostracods are still limited (Elofson, 1941; Cronin et al., 1991; Jørgensen et al., 1999; Schornikov, 2001; Chavtur, 1983, 2001; Simstich et al., 2004). Most publications provide only species lists without illustrations. Some are devoted to the taxonomic description of a certain taxonomic group, which constitutes only a minor part of the Kara Sea ostracodal association (Chavtur, 1983). In several expeditions to the Kara Sea carried out between 1999 and 2001 in the frame of the joint Russian–German research project SIRRO (Siberian River Run-Off) abundant new samples were collected. We use coretop samples obtained from various depths in the river-affected eastern part of the Kara Sea (Fig. 1) in order to analyze taxonomic composition and modern distributional patterns of the various ostracodal assemblages.

In 2004 and 2005 ostracod-bearing sediments were also collected from the eastern Laptev Sea shelf and coastal thermokarst lagoons close to the Lena River

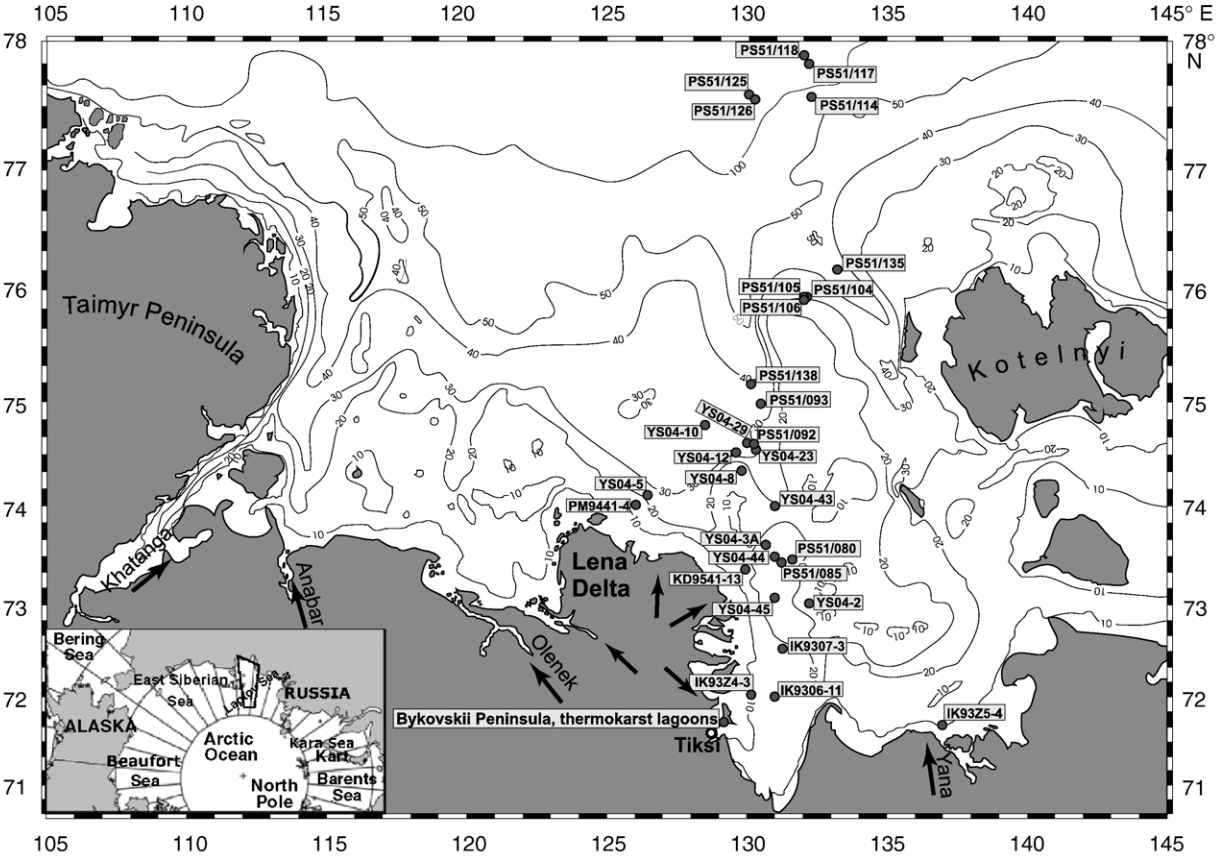

Fig. 2. Sampling locations in the Laptev Sea.

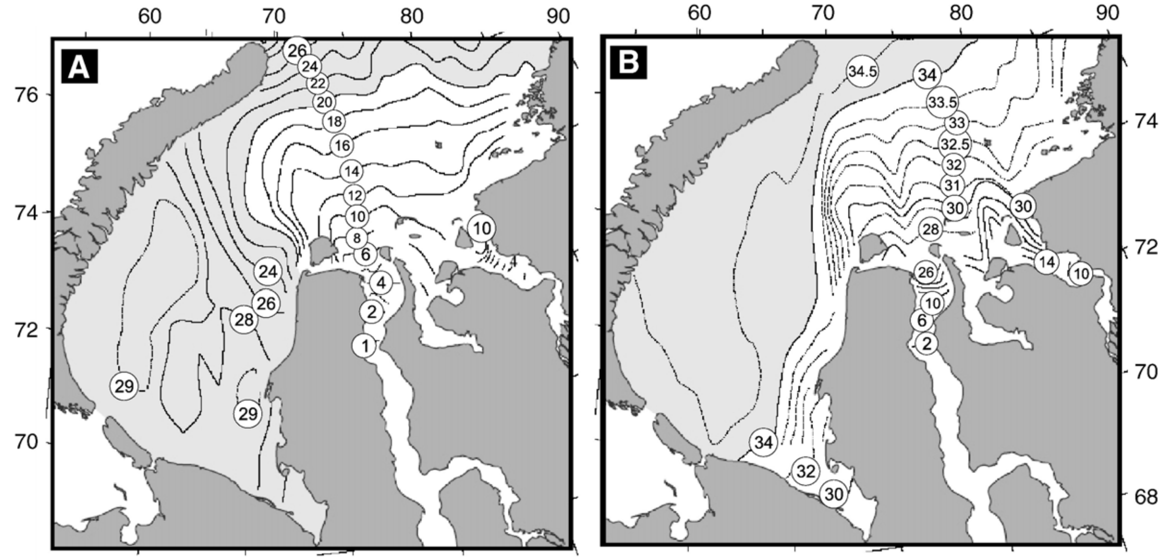

Fig. 3. Average multi-annual summer surface (A) and bottom (B) salinities in the Kara Sea (after Polyak et al., 2002).

channel (Fig. 2). Studying species from these samples enhanced our knowledge on the distribution of ostracods in the eastern Laptev Sea. Finally, we combine all assemblage data from the Kara and Laptev seas in an attempt to work out the general pattern of the ostracodal distribution in the river-affected Arctic marginal seas.

2. Modern environmental setting

The eastern Kara and Laptev seas are typical marginal Arctic seas largely represented by vast shallow shelves gently sloping northward down to water depths of 100 m. In the eastern Kara Sea, the deep St. Anna and Voronin troughs cut the outer shelf. A remarkable feature of the shelf topography in the Laptev and Kara seas is the presence of several paleo-river valleys stretching towards the shelf break (Dittmers et al., 2003). In the Laptev Sea, the permafrost coasts are actively retreating due to intensive thermoabrasion (Rachold et al., 2000), and coastal thermokarst lagoons are formed in place of former thermokarst lakes.

The major part of the Kara and Laptev seas is ice-covered from October–November until May–June. In winter, a continuous fast ice cover with a mean thickness of 1.8 m bounds the eastern shallow coastal zones approximately along the 20–25 m isobaths. Further to the north the fast ice is usually separated from the drift ice by open-water leads, the so-called polynyas (Pavlov and Pfirman, 1995; Dmitrenko et al., 2000).

The temperature of the bottom water is below 0 °C nearly all year round. Only in the troughs and on the continental slope at water depths below 75–100 m does the temperature rise up to 1.0–1.5 °C due to the inflow of warmer Atlantic waters (Dobrovol’skii and Zalogin, 1982; Pavlov et al., 1996; Pavlov and Pfirman, 1995). In summer, bottom water temperatures of the Ob’ and Yenisei estuaries increase as a result of the warm river water (Pivovarov et al., 2003; Simstich et al., 2005a,b).

Eastern parts of the Kara and Laptev seas (Figs. 1 and 2) are subject to extremely strong runoff influence of the three biggest Arctic rivers, the Ob’, Yenisei and Lena, which discharge approximately 400, 580 and 530 km^3 of freshwater per year, respectively (Gordeev, 2000). Due to the considerable river runoff in summer and ice formation in winter salinity is the most variable feature affecting the spatial distribution of benthic organisms. Surface water salinities range from less than 5[1] in the estuaries down to 28–30 in the distant areas (Figs. 3A and 4A). Because of the prevention of vertical mixing by the low-density freshwater outflow bottom water salinities are less variable. In the Kara Sea, they range from 10–15 in the outer estuaries of the Ob’ and Yenisei down to 34 in the outer shelf zone (Fig. 3B). The lowest average bottom salinities

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[1] Salinity is given without units using the Practical Salinity Scale (Millero, 1993). All salinity measurements, besides the thermokarst lagoons, were made with CTD-probes (Conductivity–Temperature–Depth). In the thermokarst lagoons salinity was measured by conductivity apparatus as the electrical conductivity of water.

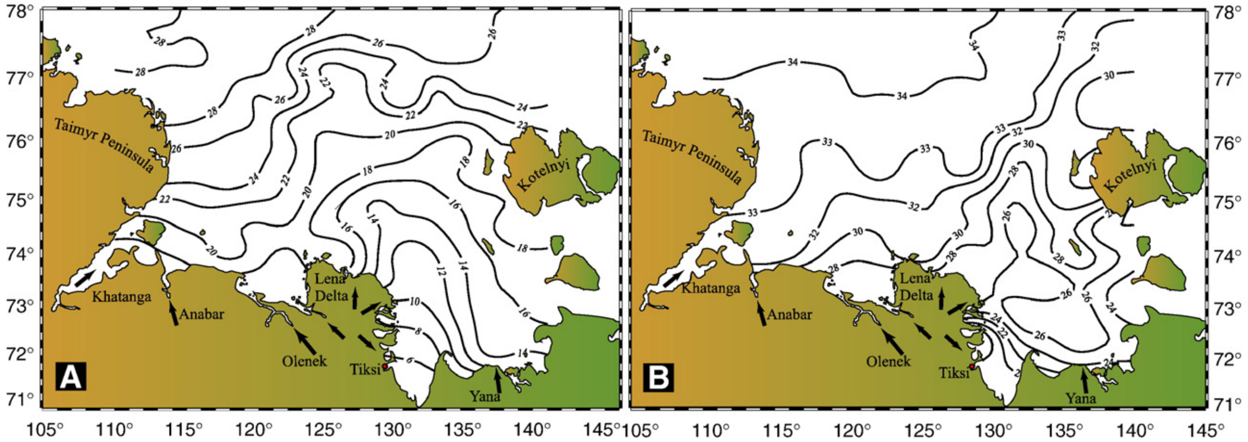


Fig. 4. Average multi-annual summer surface (A) and bottom (B) salinities in the Laptev Sea (after Stepanova et al., 2003).

in the southeastern Laptev Sea close to the Lena delta are around 18–20, whereas further offshore bottom salinities increase up to 34 on the outer shelf and upper continental slope (Fig. 4B). However, close to river mouths and in a very narrow zone adjacent to them, salinity is even lower than 18–20 (Petryashov et al., 1999). In the Kara Sea, due to the localized area of riverine and marine waters mixing the well-developed salinity fronts are located north of the estuaries, where bottom salinity sharply increases from 10–15 to 30 (Fig. 3B). In the southeastern Laptev Sea, where the Lena river outflow enters the sea through several deltaic channels, salinity fronts restricted to river mouths are smaller than in the Kara Sea and not seen in the average bottom salinity chart (Fig. 4B). Not only does river runoff affect salinity variations in the shallow shelf zone, it also controls sedimentation processes, sea-ice extent, and biological productivity. The strong linear correlations of the mean hydrographic bottom water variables (summer and winter salinities, winter temperature, oxygen concentration) with the surface water salinity reflect a generalized riverine signal (Polyak et al., 2002). Similarly, the inverse correlation between the surface salinity and primary production, chlorophyll *a* concentration, and total sediment load confirm the strong influence of riverine input on the shelf environment (Polyak et al., 2002).

3. Materials and methods

A total of 71 sediment samples were collected from different water depths (11 to 295 m) in the eastern Kara Sea during expeditions aboard R/V ‘‘Boris Petrov’’ in August–September of 1999 (BP99), 2000 (BP00), and 2001 (BP01) (Fig. 1, Table 1). Coretop samples representing the upper 2 cm of sediment were obtained using a large box corer. They were washed over a 63-μm sieve and dried. Ostracods were picked, identified, and counted. All samples from BP01 expedition (36) and some samples from BP99 expedition (3) were studied only for species composition. In the rest 32 samples from BP99 and BP00 expeditions also the total concentration was calculated (specimens per 100 g dry bulk sediment). Most samples from BP99 and BP00 expeditions were stained with Rose Bengal to estimate the share of dead and living valves (Table 1). In total 2570 valves and 414 carapaces were collected, forty-five species identified, twenty-seven species reported for this area for the first time (Table 2). SEM photos of all identified species are provided (Plates I–V). The entire collection is stored at the Paleontological Institute in Moscow.

In 2004, coretop sediment samples were collected in the shallow eastern Laptev Sea shelf (water depths 13 to 37 m) during TRANSDRIFT X expedition aboard R/V “Yakov Smirnitskii” (Fig. 2, Table 1). The samples representing the upper 2 cm of sediment were obtained using a grab sampler, and treated as described above. Ostracods were found in 11 samples. The total concentration of ostracods per 100 g dry bulk sediment was estimated as well as the percentage of dead valves. We added the data on these new samples to the existing database (Stepanova et al., 2003, 2004). In total, for the eastern Laptev Sea we analyze data on 31 samples collected during TRANSDRIFT I, II, III, V and X expeditions covering a water depth range from 11 to 127 m.

In spring 2005, coretop samples (0–1 cm) were collected from cores drilled in two coastal thermokarst

Table 1
Site locations, hydrography, some characteristics of ostracod samples

NN	Cruise	Station	Water depth (m)	Latitude (°N)	Longitude (°E)	Bottom salinity	Total ostracod abundance (valves per 100 g dry bulk sediment)	Dead ostracod specimens (%)	Juvenile specimens (%)
Kara Sea									
1	BP99	01	27	74.50	74.00	32.10	72	2	35
2	BP99	02	35	74.50	75.92	32.20	47	5	25
3	BP99	03	37	74.00	80.01	33.00	398	5	24
4	BP99	06	11	72.29	80.03		1	0	0
5	BP99	11	41	73.77	79.99	32.10	196	5	24
6	BP99	12	25	73.76	79.48	32.00	4	12	63
7	BP99	13	36	74.50	78.00	33.10	86	11	27
8	BP99	17	16	72.86	73.94	30.40	31	100	11
9	BP99	19	14	72.19	74.19	21.10	60	0	0
10	BP99	20	16	72.51	74.73	27.30	270	0	25
11	BP99	21	17	73.24	74.03	30.15	10	10	17
12	BP99	24	21	73.46	74.87	29.70	34	14	21
13	BP99	25	26	74.00	74.00	32.00	74	10	40
14	BP99	28	23	73.42	78.81	29.50	111	0	41
15	BP99	29	17	73.09	78.51	28.20	38	0	13
16	BP99	31	17	72.49	79.76	29.70	36	6	17
17	BP99	32	27	73.13	79.95	31.50	750	0	30
18	BP99	35	34	74.30	78.33	33.00	10	100	57
19	BP99	37	30	74.30	74.33	32.24	4	0	25
20	BP99	38	31	74.25	75.61	32.10	35	12	34
21	BP99	39	38	74.30	76.83	32.73	70	10	23
22	BP00	05	55	75.84	81.01	33.55	55	30	39
23	BP00	07	43	74.66	81.14	33.00	72	10	10
24	BP00	08	46	74.66	82.64	33.29	67	10	25
25	BP00	09	49	74.83	83.43	33.50	140	5	14
26	BP00	15	11	72.05	81.60	19.20	1	50	0
27	BP00	20	25	71.04	83.20	2.88	7	0	0
28	BP00	22	16	72.57	79.92	30.50	70	30	25
29	BP00	23	38	73.50	79.86	32.52	89	30	21
30	BP00	27	83	76.30	78.93	34.20	147	10	28
31	BP00	28	55	76.66	83.88	34.00	75	4	32
32	BP00	29	73	76.94	85.76	34.20	139	0	21
33	BP00	31	48	75.46	82.55	33.71	263	16	35
34	BP00	32	37	75.26	84.34	33.07	104	15	13
35	BP00	35	51	75.35	83.80	33.50	26	0	27
36	BP01	11	12	72.09	81.70	14.19			0
37	BP01	14	21	71.82	82.45	13.67			0
38	BP01	19	28	72.59	80.11	23.98			0
39	BP01	20	16	72.59	80.52				0
40	BP01	24	37	73.63	80.00				0
41	BP01	26	33	74.00	80.02	32.74			0
42	BP01	28	51	75.94	89.27	33.36			0
43	BP01	30	47	76.41	88.18	34.13			10
44	BP01	31	88	77.57	87.91	34.24			0
45	BP01	32	92	77.46	87.44	34.34			
46	BP01	34	92	77.90	88.33	34.28			0
47	BP01	35	160	77.90	83.77	34.70			54
48	BP01	37	129	77.81	86.20	34.46			17
49	BP01	38	97	77.09	86.93	34.31			11
50	BP01	40	46	76.42	85.67	34.13			27
51	BP01	41	38	75.69	87.13	32.79			0
52	BP01	43	43	75.38	85.83	33.23			7
53	BP01	45	77	77.11	84.73	33.93			18
54	BP01	46	295	77.92	75.96	34.88			0
55	BP01	47	174	77.92	77.37				50
56	BP01	48	182	77.89	81.50	34.33			24

Table 1 (*continued*)

NN	Cruise	Station	Water depth (m)	Latitude (°N)	Longitude (°E)	Bottom salinity	Total ostracod abundance (valves per 100 g dry bulk sediment)	Dead ostracod specimens (%)	Juvenile specimens (%)
Kara Sea									
57	BP01	51	158	77.91	79.49	34.52			25
58	BP01	52	68	77.50	79.87	34.25			40
59	BP01	55	73	77.05	79.73	34.03			10
60	BP01	56	162	76.99	75.19	34.80			24
61	BP01	58	84	76.80	78.35	34.11			29
62	BP01	59	173	76.52	74.52	34.38			20
63	BP01	61	101	76.22	75.89	34.06			0
64	BP01	62	120	76.20	74.20	34.30			22
65	BP01	65	57	75.72	75.84	33.84			23
66	BP01	66	51	75.19	76.92	33.76			0
67	BP01	68	28	74.58	72.25	31.84			0
68	BP01	72	24	70.83	73.74	1.98			
69	BP01	73	14	68.92	73.67	0.05			0
70	BP01	80	15	72.25	73.25	10.43			17
71	BP01	82	27	73.20	73.03	30.76			
Laptev Sea									
1	YS04	02	13	73.00	132.27		17	18	
2	YS04	03A	23	73.60	130.75		8	0	
3	YS04	05	26	74.12	126.42		91	38	
4	YS04	08	18	74.35	129.92		20	0	
5	YS04	10	35	74.82	128.58		2	100	
6	YS04	12	37	74.52	129.70		51	41	
7	YS04	23	32	74.55	130.32		9	20	
8	YS04	29	32	74.62	130.02		15	50	
9	YS04	43	22	74.00	131.00		20	50	
10	YS04	44	25	73.50	131.00		56	54	
11	YS04	45	24	73.08	131.00		10	37	
12	PS51	080-11	21	73.47	131.65	23.41	600	15	
13	PS51	085-2	22	73.57	131.27	27.90		2	
14	PS51	092-11	34	74.60	130.13	32.43	307	0	
15	PS51	093-1	33	74.95	130.57	32.99		0	
16	PS51	104-14	34	75.97	132.15	32.64	79	0	
17	PS51	105-3	33	75.95	132.10	32.82	55	6	
18	PS51	106-1	33	75.95	132.07			10	
19	PS51	114-13	66	77.60	132.27	33.78	228	1	
20	PS51	117-3	76	77.83	132.23	34.11	162	8	
21	PS51	118-1	121	77.90	132.22		172	20	
22	PS51	125-12	127	77.62	130.00		163	5	
23	PS51	126-2	85	77.55	130.13		347	10	
24	PS51	135-2	51	76.17	133.25		73	0	
25	PS51	138-10	41	75.15	130.83	33.22	113	0	
26	IK93	06-11	18	72.00	130.98				
27	IK93	07-3	21	72.55	131.30				
28	IK93	Z4-3	14	72.03	130.13				
29	IK93	Z5-4	11	71.68	137.00				
30	PM94	41-4	14	74.00	125.98				
31	KD95	41-13	22	73.38	129.95				
Thermokarst lagoons, Bykovskii Peninsula									
Pestsovaya			2.1	71.74	129.12	Winter water salinity 19, salinity of ice 2.3		58	
Uomullyakhskaya			1.4	71.73	129.28			0	

lagoons (Pestsovaya and Uomullyakhskaya) on the Bykovskii Peninsula northeastward from Tiksi (Fig. 2, Table 2). Samples were processed as described above, the total abundance of ostracods and live/dead ratio were estimated. The water depth in Pestsovaya lagoon is 2.1 m, and ice thickness at the time of drilling was 1.8 m.

Table 2
History of investigation of the Kara Sea Ostracoda

	List of species		Elofson, 1941	Cronin et al., 1991	Jørgensen et al., 1999	Chavtur, 1983	Chavtur, 2001	Schornikov, 2001	Simstich et al., 2004	present work	Plate N	fig. N	ostracod species according to their salinity and water depth preferences				
		water depth, m	30–140	223–441	17–43	<360	unknown	unknown	11–160	11–295			fresh-water	brackish-water	euryhaline	marine shallow-water	marine deep-living
1	Pseudocythere caudata			+						+	1	1					+
2	Bythocythere sp.1									+	1	3					+
3	Bythocythere constricta			+						+	1	2					+
4	Jonesia acuminata									+	1	4–5					
5	Sclerochilus sp.1									+	1	6				+	
6	Cluthia cluthae									+	1	7–8				+	
7	Cytheropteron arcuatum			+						+	1	9–10					+
8	Cytheropteron champlainum									+	1	11–12					+
9	Cytheropteron elaeni			+						+	1	13–14				+	
10	Cytheropteron montrosiense									+	1	15				+	
11	Cytheropteron nodosoalatum			+						+	2	3–4				+	
12	Cytheropteron occultum									+	2	1–2					+
13	Cytheropteron paralatissimum			+						+	2	5					+
14	Cytheropteron sulense									+	2	6–7				+	
15	Cytheropteron suzdalskyi									+	2	8–9				+	
16	Cytheropteron tumefactum			+						+	2	10,13					+
17	Semicytherura complanata									+	2	11–12				+	
18	Semicytherura sp.1									+	2	14				+	
19	Palmenella limicola			+						+	2/3	15/1				+	
20	Roundstonia globulifera			+						+	3	2				+	
21	Cytheromorpha macchesneyi			+					+	+	3	3–4		+			
22	Pteroloxa cumuloidea									+	3	5		+			
23	Acanthocythereis dunelmensis			+				+		+	3	6–7				+	
24	Rabilimis mirabilis							+		+	3	8–9				+	
25	Sarsicytheridea bradii			+				+		+	3	10–12				+	
26	Sarsicytheridea punctillata		+	+				+	+	+	3	13–14				+	
27	Sarsicytheridea macrolaminata?									+	4	5–6				+	
28	Heterocyprideis sorbyana		+	+				+	+	+	3	15, 17			+		
29	Heterocyprideis fascis									+	4	1–2			+		
30	Eucythere argus									+	4	3				+	
31	Paracyprideis pseudopunctillata								+	+	3/4	16, 18/4			+		
32	Pontocythere sp.1									+	4	9				+	
33	Krithe glacialis									+	4	10–12					+
34	Argilloecia cylindrica									+	4	14					+
35	Argilloecia conoidea			+						+	4	13					+
36	Argilloecia spp.									+	4	15–16					+
37	Elofsonella concinna									+	4/5	17/1				+	
38	Normanicythere leioderma			+						+	5	2–4				+	
39	Cytheretta teshekpukensis									+	5	5–7				+	
40	Polycope spp.									+	5	13–14					+
41	Philomedes brenda					+				+	5	12					+
42	Candona harmsworthi									+	5	8	+				
43	Cytherissa lacustris									+	4	7–8	+				

Table 2 (*continued*)

List of species	Elofson, 1941	Cronin et al., 1991	Jørgensen et al., 1999	Chavtur, 1983	Chavtur, 2001	Schornikov, 2001	Simstich et al., 2004	present work	Plate N	fig. N	ostracod species according to their salinity and water depth preferences				
water depth, m	30–140	223–441	17–43	<360	unknown	unknown	11–160	11–295			fresh-water	brackish-water	euryhaline	marine shallow-water	marine deep-living
44 Candona sp. juv.1								+	5	9–10	+				
45 Candona sp. juv.2		+						+	5	11	+				
46 Cythere lutea		+													
47 Baffinicythere howei		+													
48 Cytheropteron arcticum		+													
49 Cytheropteron alatum		+													
50 Cytheropteron hamatum		+													
51 Cytheropteron inflatum		+													
52 Cytheropteron pararcticum		+													
53 Cytheropteron angualatum		+													
54 Cytheropteron pyramidale		+													
55 Cytheropteron spp.		+													
56 Finmarchinella barentzovoensis		+													
57 Finmarchinella finmarchica		+													
58 Finmarchinella angulata		+													
59 Finmarchinella logani		+													
60 Loxoconcha venepidermoidea		+													
61 Hemicythere emarginata		+													
62 Hemicytherura clathrata		+													
63 Paradoxostoma spp.		+													
64 Rabilimis septentrionalis		+													
65 Sarsicytheridea marcolaminata		+													
66 Sclerochilus contortus		+													
67 Semicytherura aff. complanata		+													
68 Semicytherura affinis		+													
69 Semicytherura concentrica		+													
70 Semicytherura striata		+													
71 Semicytherura undata		+													
72 Tetracytherura? sp. A		+													
73 Xestoleberis depressa															
74 Polycope pseudoinornata				+	+										
75 Pseudopolycope akatovae				+	+										
76 P. sadcoiensis				+	+										
77 Obtusoecia obtusata					+										
78 Boroecia maxima					+										
79 B.borealis					+										
80 Discoconchoecia elegans					+										
81 Philomedes globosa globosa			+	+											

Ecological preferences of species.
Grey shading indicaes species in the Kara sea for the first time.

Salinity in the 30-cm thick water layer was estimated as 19. Uomullyakhskaya lagoon is 1.4 m deep, and was completely covered by ice when drilled.

Salinity is a major control on ostracod distribution in Arctic marginal marine environments (Athersuch et al., 1989; Neale, 1988). Percentages of different ecological

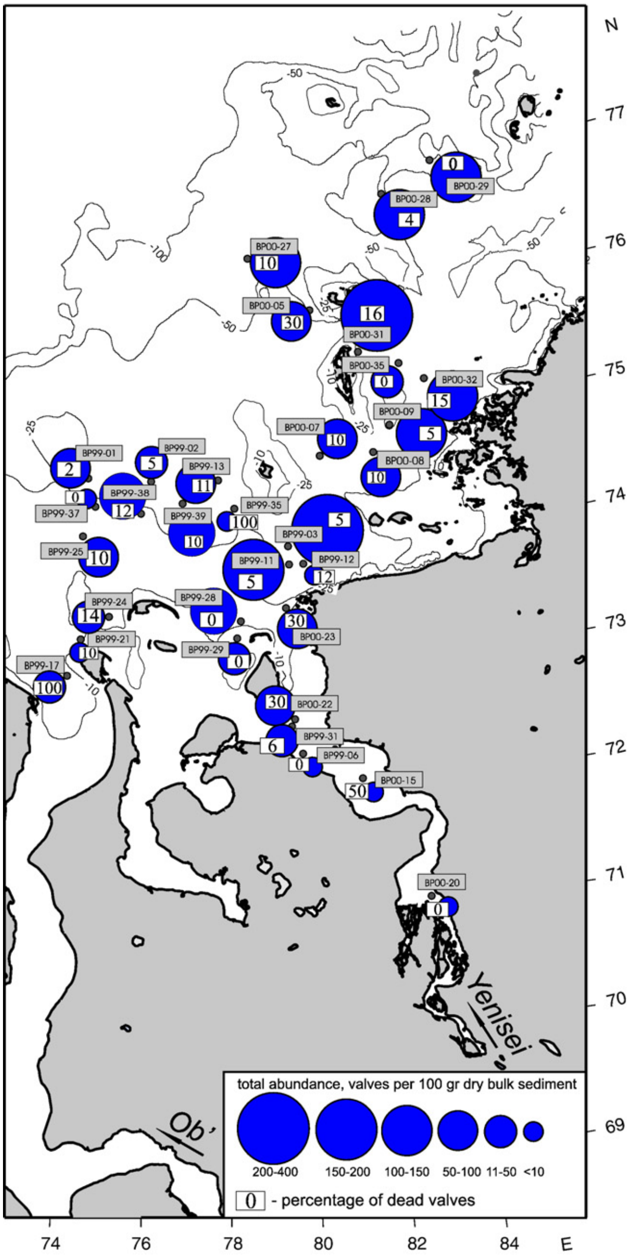


Fig. 5. Total abundance of ostracods (specimens per 100 g dry bulk weight) and percentages of dead valves in coretop samples from the eastern Kara Sea.

groups of species in relation to salinity (freshwater, brackishwater, euryhaline and marine-shallow-water and deep-living) were calculated for all studied samples and related to the Venice system (1959): hyperhaline (>40), euhaline (40–30), mixohaline (30–0.5), polyhaline (30–18), mesohaline (18–5), oligohaline (5–0.5), limnetic or freshwater (<0.5). Ecological characteristics of the species found in our samples are based on our data from the Laptev Sea (Stepanova et al., 2003, 2004; Stepanova, 2006) and published evidence from other Arctic and high-latitudinal seas (Cronin, 1989; Cronin et al., 1991, 1994; McDougall et al., 1986; Neale, 1988; Brouwers, 1990, 1994; Brouwers et al., 2000; Lev, 1983; Kupriyanova, 1999; Nikolaeva, 1989; Neale and Howe, 1975; Schornikov, 2004; Whatley et al., 1996, 1998; Athersuch et al., 1989). Generally the ecological

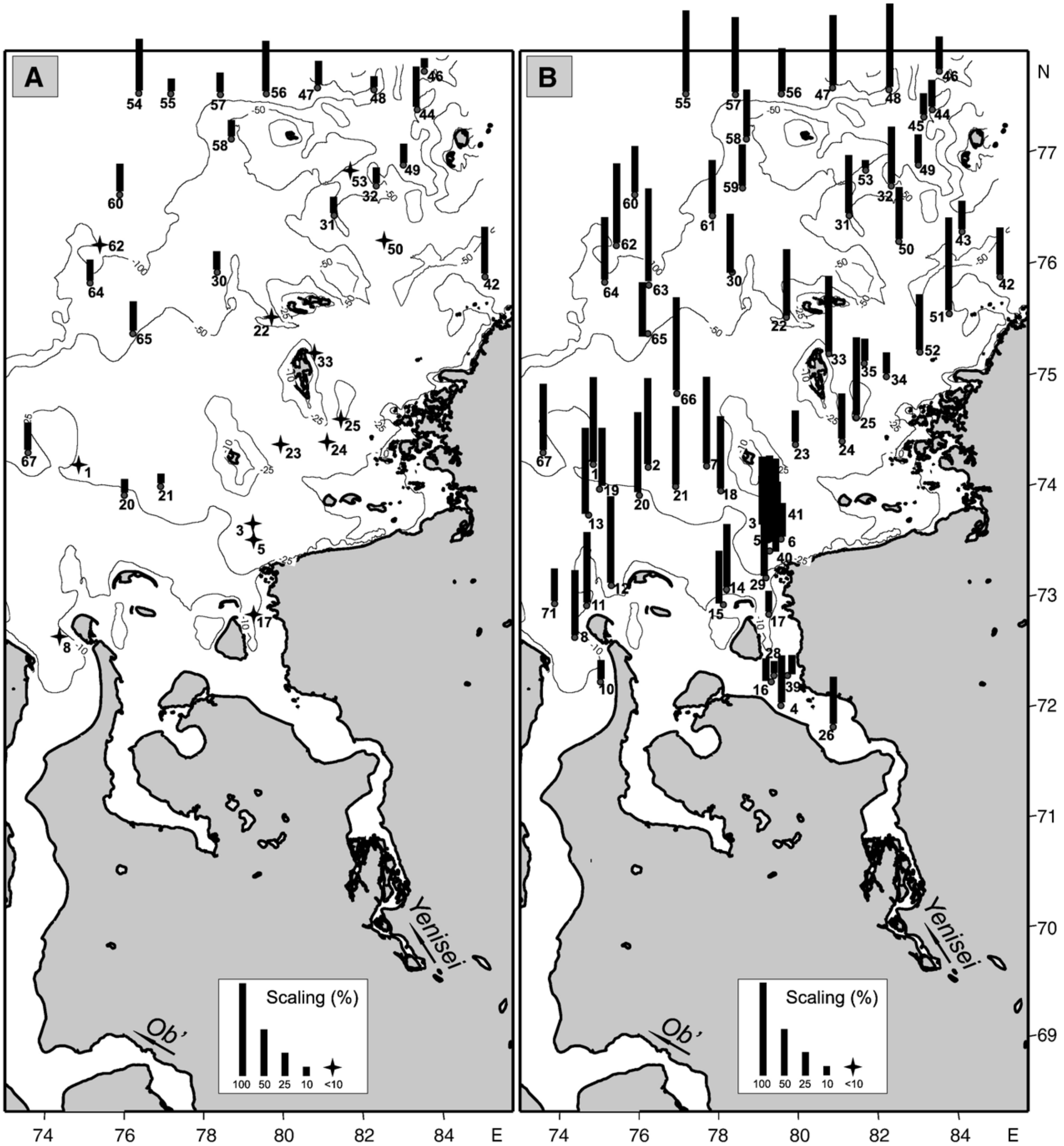


Fig. 6. Relative abundance of deep-water marine (A) and shallow-water marine (B) species in coretop samples from the eastern Kara Sea. Station numbers according to numerical order of stations given in Tables 1 and 3.

groups distinguished by us (for species affiliations see Table 2) correspond to the following salinity ranges: marine species occur in euhaline waters (deep-living taxa) and eupolyhaline waters (shallow-water taxa), euryhaline species (*Paracyprideis pseudopunctillata*, *Heterocyprideis sorbyana*, *H. fascis*) tolerate a wide salinity range (between 5 and 35) and live in different waters from meso- to euhaline; brackishwater species (*Cytheromorpha macchesneyi* and *Pteroloxa cumuloidea*) correspond to mesohaline waters; fresh-water species are found in oligohaline and fresh waters.

Table 3
Distribution of ostracod species in the Kara Sea surface sediment samples

NN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Expedition, BP	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	00	00	00	00	00	00	00	00	00	00	00	00	00	00	01
Station	1	2	3	6	11	12	13	17	19	20	21	24	25	28	29	31	32	35	37	38	39	5	7	8	9	15	20	22	23	27	28	29	31	32	35	11
Acanthocythereis dunelmesis	2	6	1		1		8							1			9	23		4	11	5							5				1			
Argilloecia conoidea																																				
A. cylindrica					2															14	10												1			
Argilloecia sp.	3																						6								2					
A. conoidea?			2																																	
Bythocythere constricta																																				
Bythocythere sp.1																																	1			
Cluthia cluthae	11	17	19		21		10					24	4	5	3		3	10	25	25	24	1	17	22	35			1	10	6	2	1	13	16	5	
Cytheretta teshekpukensis											14																									
Cytheromorpha macchesneyi					1			11	100	25						36			25					3		50		27								100
Cytheropteron arcuatum																	3													2	3	5				
C. champlainum						12																			3								1			
C.elaeni	1	2	1		3		24					4	27							16	19				3				31				1			
C. montrosiense							1																													
C. nodosoalatum		2																													3					
C. occultum								6																												
C. paralatissimum																																	3			
C. sulense					25			66		10		6				8																				
C. suzdalskyi							17						2				7			4	1								5							
C. tumefactum																																				
Elofsonella concinna		4	1																			8			3						2	3	5			
Eucythere argus								3								8												1								
Heterocyprideis fascis											15																				13	15				
H. sorbyana	3	2				64	1	3			10	1	4	29	8			23				12		3	1			3			6	7	2			
Jonesia acuminata	3											3	2					10						1									1			
Krithe glacialis																						9		2	1					17	12	10	1			
Normanicythere leioderma	12																					12									6	4				
Palmenella limicola		2			7		3					11	3		5	8	2				3		10	3	3				1	4						
Paracyprideis pseudopunctillata			25				1	11		55		6	1		36	40	76		13		6	6	61	44	13			58	20	17			10	75	77	
Pontocythere sp.1											10																									
Pseudocythere caudata																																1	1			
Pteroloxa cumuloidea																																				
Rabilimis mirabilis			1	50											9							2			4					14	4	10	3		9	
Roundstonia globulifera			1		2		3				17	6	1		5					9			6					5	5							
Sarsicytheridea bradii	55	58				24					34	20	55	58	13			19	37	14		28		16	25			1		23	22	10	46	6	9	
S. macrolaminata?	3	4												3								2			2						2	1		3		
S. punctillata			1											2				10				11								10	22	30				
Sclerochilus sp.																															1					
Semicytherura complanata	7	3	48		38		32			10		19	1	1	21			5		14	26	4		6	7	50			23	6		2	10			
Semicytherura sp.1																												4								
Philomedes brenda																																				
Polycope spp.														1																						
Candona harmsworthi																																				
Candona sp.1 juv.																											100									
Candona sp.2 juv.																																				
Cytherissa lacustris																																				
Undetermined				50																										1		1				

Table 3 (*continued*)

NN	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
Expedition, BP	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01
Station	14	19	20	24	26	28	30	31	32	34	35	37	38	40	41	43	45	46	47	48	51	52	55	56	58	59	61	62	65	66	68	72	73	80	82
Acanthocythereis dunelmesis				100					8								4														14				
Argilloecia conoidea												9						18	2					5											
A. cylindrica																						4		3					3		29				
Argilloecia sp.																																			
A. conoidea?																																			
Bythocythere constricta																		19																	
Bythocythere sp.1																																			
Cluthia cluthae									2		6	5				40			2					3					5	100					
Cytheretta teshekpukensis																																			
Cytheromorpha macchesneyi			33																													100			
Cytheropteron arcuatum									2										3	18	6	5		8					5						
C. champlainum																																			
C.elaeni																															43				
C. montrosiense																								4											
C. nodosoalatum																																			
C. occultum																																			
C. paralatissimum																													2						
C. sulense			11																																
C. suzdalskyi									9																						14				
C. tumefactum											10								4	36				8											
Elofsonella concinna								28																											
Eucythere argus																																			
Heterocyprideis fascis													20																						
H. sorbyana	15						30			40			30	20			20	45				12	25	22				11	4					73	
Jonesia acuminata																																			
Krithe glacialis					33			29			15	2	20	5			4		4		8	4		5		7		11	21						
Normanicythere leioderma																																			
Palmenella limicola																																			
Paracyprideis pseudopunctillata			47						1																										34
Pontocythere sp.1					33		40	29	78	16				20		41	68					21	31		43	8			6					16	66
Pseudocythere caudata																																			
Pteroloxa cumuloidea		100																																	
Rabilimis mirabilis																																		11	
Roundstonia globulifera						50	10			14	5	7		5	100				7	18	28	4	44	12	43	77		56	29						
Sarsicytheridea bradii																																			
S. macrolaminata?																																			
S. punctillata																																			
Sclerochilus sp.							20			20	64	72	30	50			4		75	28	52	43		30	14	8		11	13						
Semicytherura complanata			9																																
Semicytherura sp.1					34							5				19			3			3					100		11						
Philomedes brenda																																			
Polycope spp.								14														4													
Candona harmsworthi						50				10								18			6							11							
Candona sp.1 juv.																																	18		
Candona sp.2 juv.	85																																36		
Cytherissa lacustris																																	46		
Undetermined																													1						

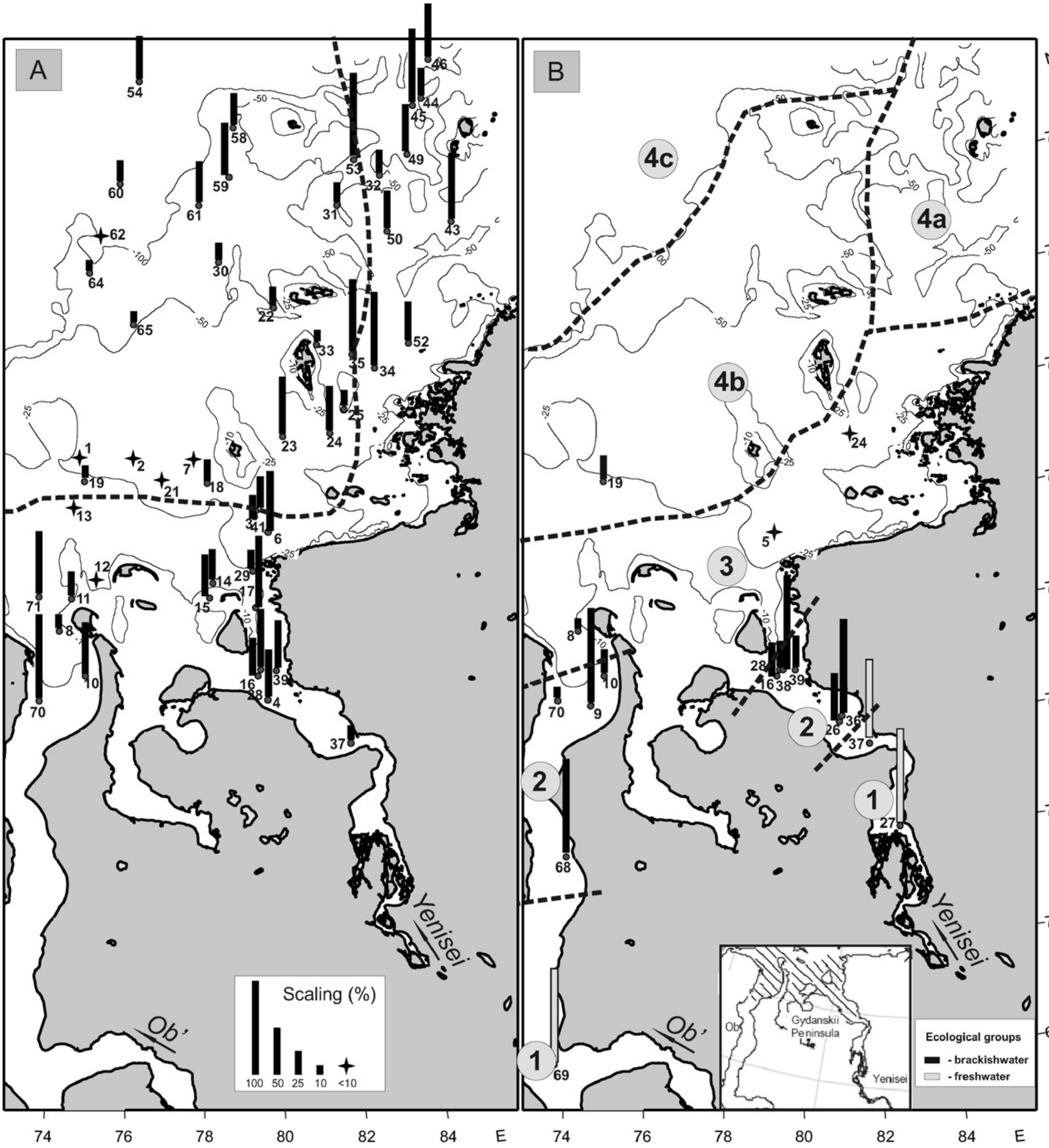
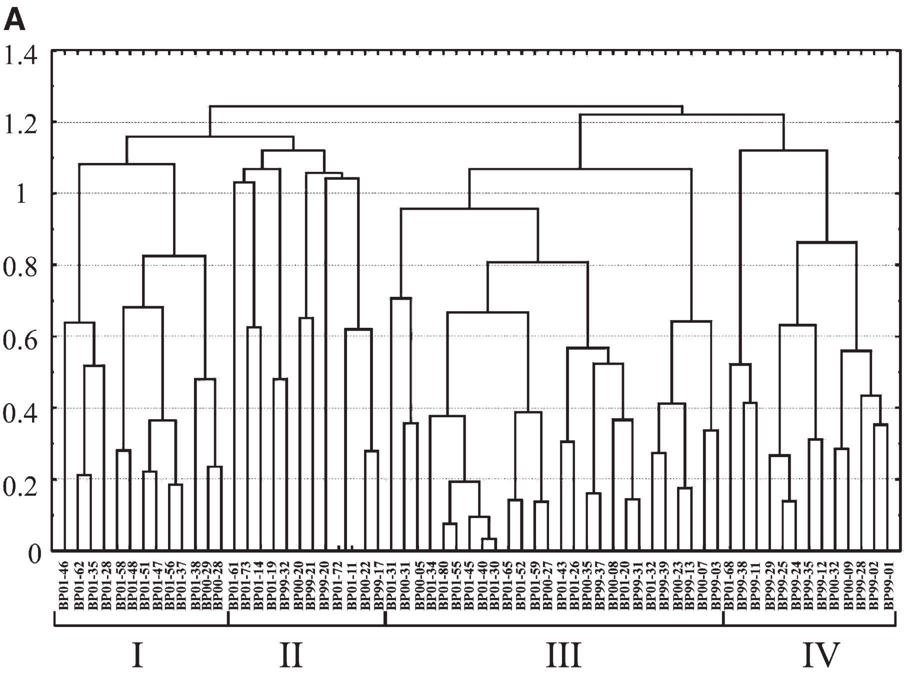


Fig. 7. Relative abundance of euryhaline (A) and brackishwater together with freshwater (B) species in coretop samples from the eastern Kara Sea. Ostracodal assemblages in the eastern Kara Sea (B). Station numbers according to numerical order of stations given in Tables 1 and 3. Dotted line in A shows the average position of fast-ice margin (after Pavlov and Pfirman, 1995). Dotted line in Fig. 7B shows tentative boundaries between ostracodal assemblages. Hatched area in the insert in B shows the location of the marginal filter zone in the Kara Sea (after Stein et al., 2004).

By applying cluster analysis, the studied ostracod samples from the Kara Sea were grouped in relation to their geographical location and, hence, environmental conditions (water depth and salinity variations). The percentage data on 45 taxa from 64 samples (samples containing 1–4 specimens were excluded) were entered into the Statistica 6 software package. We used the 1-Pearson *r* coefficient and



B

cluster	dominant ecological groups	depth range	characteristic taxa
I	shallow-water marine with admixture of deep-living marine	50-295 m	*Sarsicytheridea punctillata, Rabilimis mirabilis, Argilloecia conoidea, Cytheropteron arcuatum, C. tumefactum, Krithe glacialis*
II	freshwater, brackishwater, euryhaline	11-30 m (one station BP01-61 - 101 m)	*Cytherissa lacustris, Candona harmsworthi, Cytheromorpha macchesneyi, Pteroloxa cumuloidea, Paracyprideis pseudopunctillata, Heterocyprideis sorbyana*
III	shallow-water marine euryhaline	14-172 m (most stations located at 40-80 m)	*Paracyprideis pseudopunctillata, Heterocyprideis sorbyana,* diverse shallow-marine species (*Cluthia cluthae, Semicytherura complanata, Sarsicytheridea bradii* and others)
IV	shallow-water marine	20-68 m	*Sarsicytheridea bradii, Cluthia cluthae, Cytheropteron elaeni, Semicytherura complanata, Acanthocythereis dunelmensis*

Fig. 8. Cluster analysis dendrogram (A) of 64 samples from the Kara Sea based on relative abundance of 45 ostracod taxa and description (B) of obtained clusters.

average linkage cluster method to obtain the cluster dendrograms.

4. Results

4.1. Kara Sea

4.1.1. The Kara Sea ostracod association: taxonomic composition and abundance pattern

The complete list of taxa identified in the Kara Sea with references to the plates in this work together with species identified by other authors for this area is given in Table 2. Prior to our investigations only seven publications mentioning recent ostracods from the Kara Sea were available (Elofson, 1941; Chavtur, 1983, 2001; Cronin et al., 1991; Jørgensen et al., 1999; Schornikov, 2001; Simstich et al., 2004; Table 2). Only two species were identified by Elofson (1941) from the western part of the Kara Sea, in water depths of 30 m (*H. sorbyana*) and 140 m (*Sarsicytheridea punctillata*). In the monograph of Chavtur (1983) four species of the subclass Myodocopina were described in detail. Eleven

Table 4
Distribution of ostracod species in the Laptev Sea surface sediment samples

NN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Expedition	**YS04**	**YS04**	**YS04**	**YS04**	**YS04**	**YS04**	**YS04**	**YS04**	**YS04**	**YS04**	**YS04**	**PS51**	**PS51**	**PS51**	**PS51**	**PS51**	**PS51**
Station	**2**	**3A**	**5**	**8**	**10**	**12**	**23**	**29**	**43**	**44**	**45**	**080-11**	**085-2**	**092-11**	**093-1**	**104-14**	**105-3**
Acanthocythereis dunelmensis												5				53	21
Argilloecia cylindrica		17														14	1
Argilloecia sp.						4											
Bythocythere constricta													3				
Cluthia cluthae			5						24	8					2	2	31
Cytheromorpha macchesneyi	12									8			2				
Cytheropteron arcuatum															1		4
C.biconvexa																	
C.champlainum																	
C. elaeni			5			16	20			4		5		3			
C. inflatum																	
C. montrosiense										16			17		4		
C. nodosoalatum																	2
C. perlaria																	
C. porterae																	
C. sulense											19		15	5	7		
C. suzdalskyi						8											
C. tumefactum																	
Cytheropteron sp.juv.			5														
Elofsonella concinna												2				11	16
Eucythere argus		49		71					38		19						
Heterocyprideis fascis											12						
Heterocyprideis sorbyana	35		3			3						3		5	13		
Heterocyprideis sp.						1											
Jonesia acuminata																2	7
Krithe glacialis																	
Palmenella limicola						4				4			7	3		2	
Paracyprideis pseudopunctillata	41		13		100	4	60	75		50		85		81	55		4
P. cf. *pseudopunctillata*																	
Rabilimis mirabilis										10							
R. septentrionalis																	
Sarsicytheridea bradii		34		15					38								3
S. punctillata																	
Sarsicytheridea sp.juv.			13														
Semicytherura complanata			56			60	20	25			50		33	3	3	11	11
Semicytherura spp.	12			14													
Polycope spp.													23		15	5	
Candona harmsworthi																	
Candona sp. juv.																	
Cypria sp.																	
Limnocythere sp. 1																	
Limnocythere sp. 2																	
Undetermined																	

Table 4 (*continued*)

NN	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Expedition	**PS51**	**PS51**	**PS51**	**PS51**	**PS51**	**PS51**	**PS51**	**PS51**	**IK93**	**IK93**	**IK93**	**IK93**	**PM94**	**KD95**	Pestsovaya	Uomullya–khskaya
Station	**106-1**	**114-13**	**117-3**	**118-1**	**125-12**	**126-2**	**135-2**	**138-10**	**06-11**	**07-3**	**Z4-3**	**Z5-4**	**41-4**	**41-13**		
Acanthocythereis dunelmensis	20	4	3				13									
Argilloecia cylindrica			3	1		2	2									
Argilloecia sp.		1														
Bythocythere constricta			1	3												
Cluthia cluthae	16	2	14	12	4	8	16									
Cytheromorpha macchesneyi	1							5	4		5					
Cytheropteron arcuatum	29		7	10	1	10										
C.biconvexa				3		2										
C.champlainum			1													
C. elaeni	3						14									
C. inflatum				6	3	1										
C. montrosiense																
C. nodosoalatum						6		3								
C. perlaria			5	5	2	5										
C. porterae		1	6	11	5	3										
C. sulense					1				4							
C. suzdalskyi	1							47								
C. tumefactum			2	7	3	2										
Cytheropteron sp.juv.																
Elofsonella concinna	6	6														
Eucythere argus					3											
Heterocyprideis fascis																
Heterocyprideis sorbyana		52	4	3	8	4							80			
Heterocyprideis sp.																
Jonesia acuminata	1															
Krithe glacialis		6	1	12	1	12										
Palmenella limicola							10									
Paracyprideis pseudopunctillata	10	3	3		4		20	9	88	83	95			100		
P. cf. *pseudopunctillata*													10			
Rabilimis mirabilis																
R. septentrionalis		20	2		3	37						100				
Sarsicytheridea bradii		1			10											
S. punctillata		3	33	7	40	7										
Sarsicytheridea sp.juv.																
Semicytherura complanata	13			3	1		25	36		17						
Semicytherura spp.																
Polycope spp.			15	16	11	1			4							
Candona harmsworthi															10	
Candona sp. juv.															29	70
Cypria sp.															3	
Limnocythere sp. 1															48	30
Limnocythere sp. 2															10	
Undetermined		1		1									10			

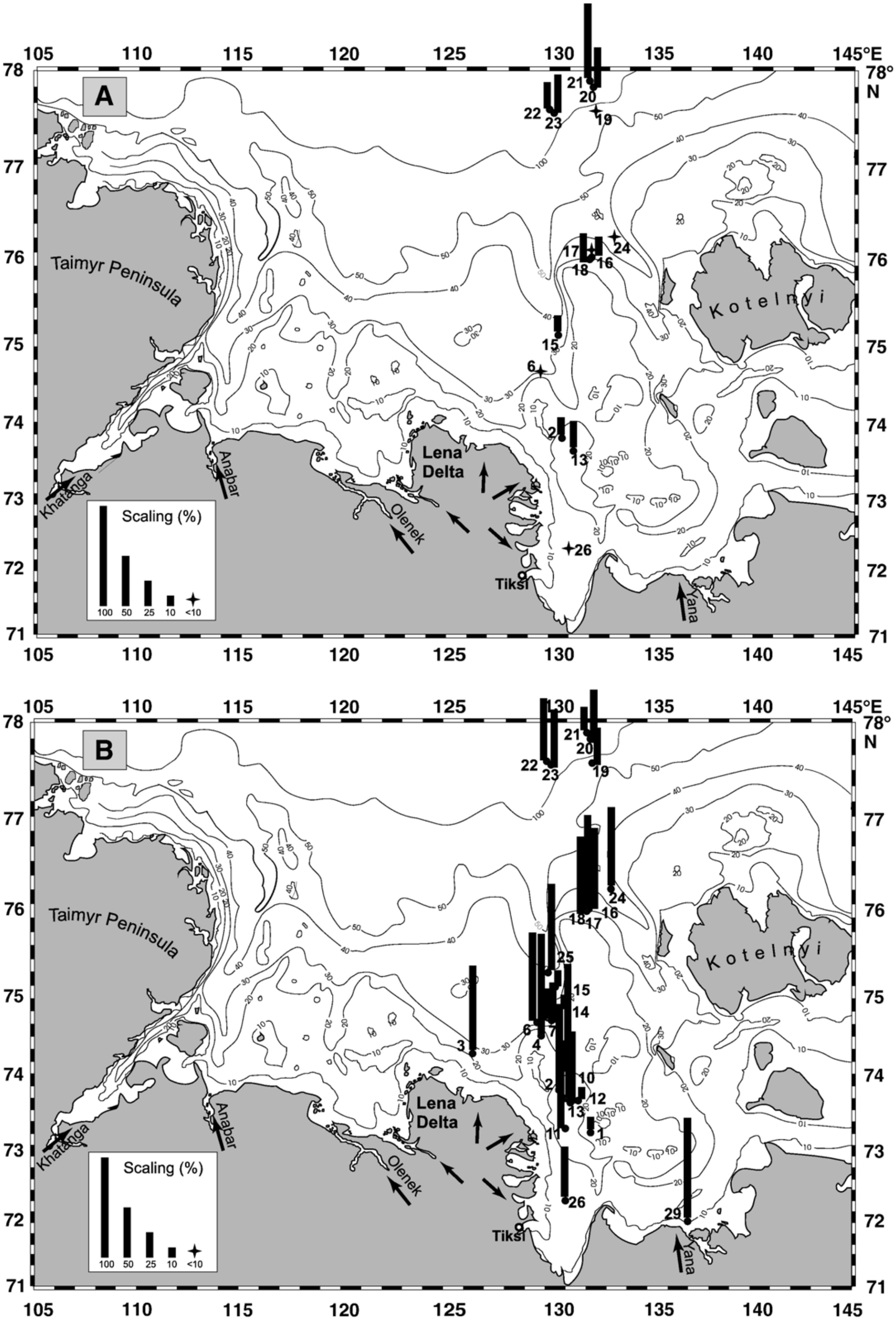


Fig. 9. Relative abundance of deep-water marine (A) and shallow-water marine (B) species in coretop samples from the eastern Laptev Sea. Station numbers according to numerical order of stations given in Tables 1 and 4.

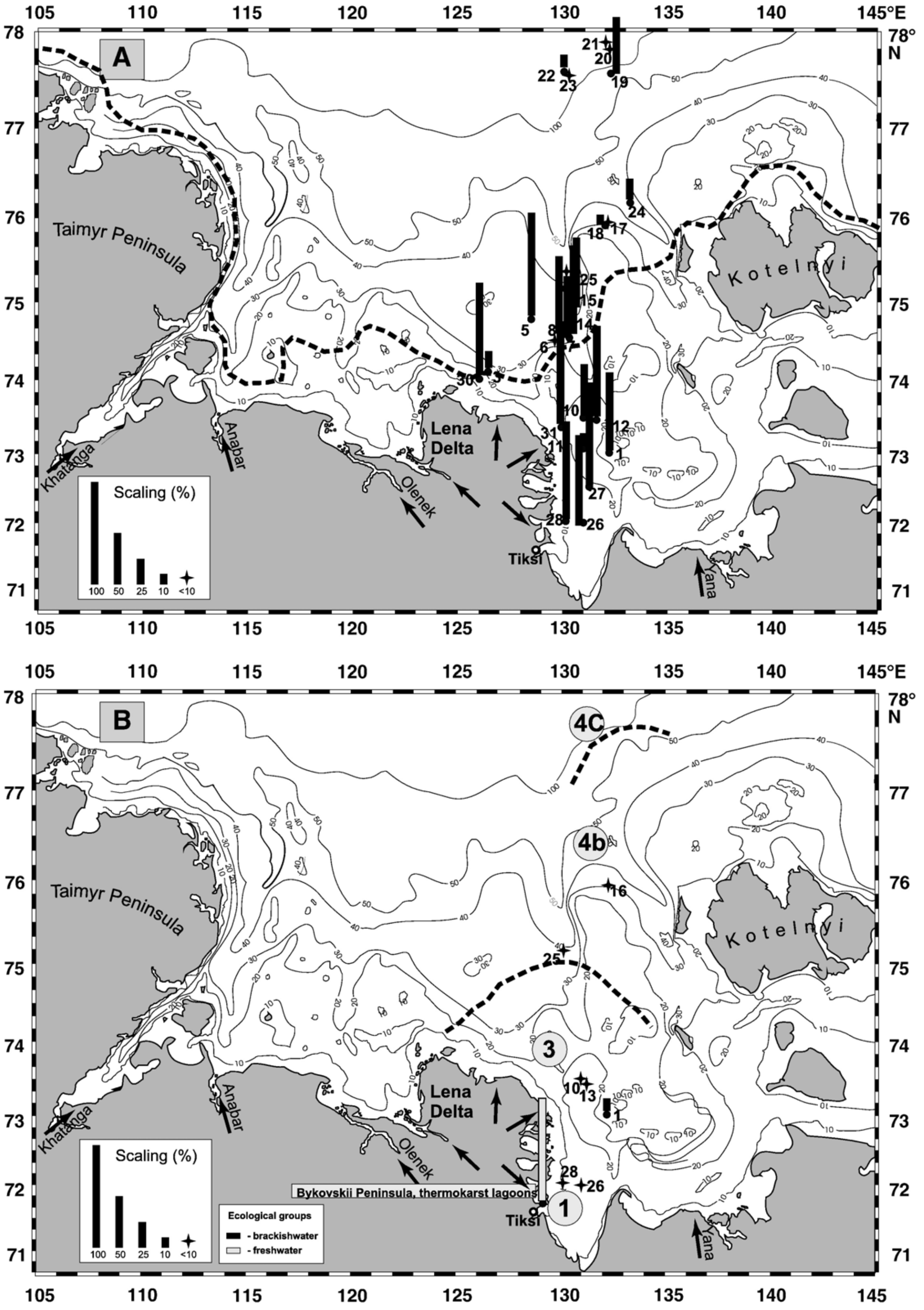
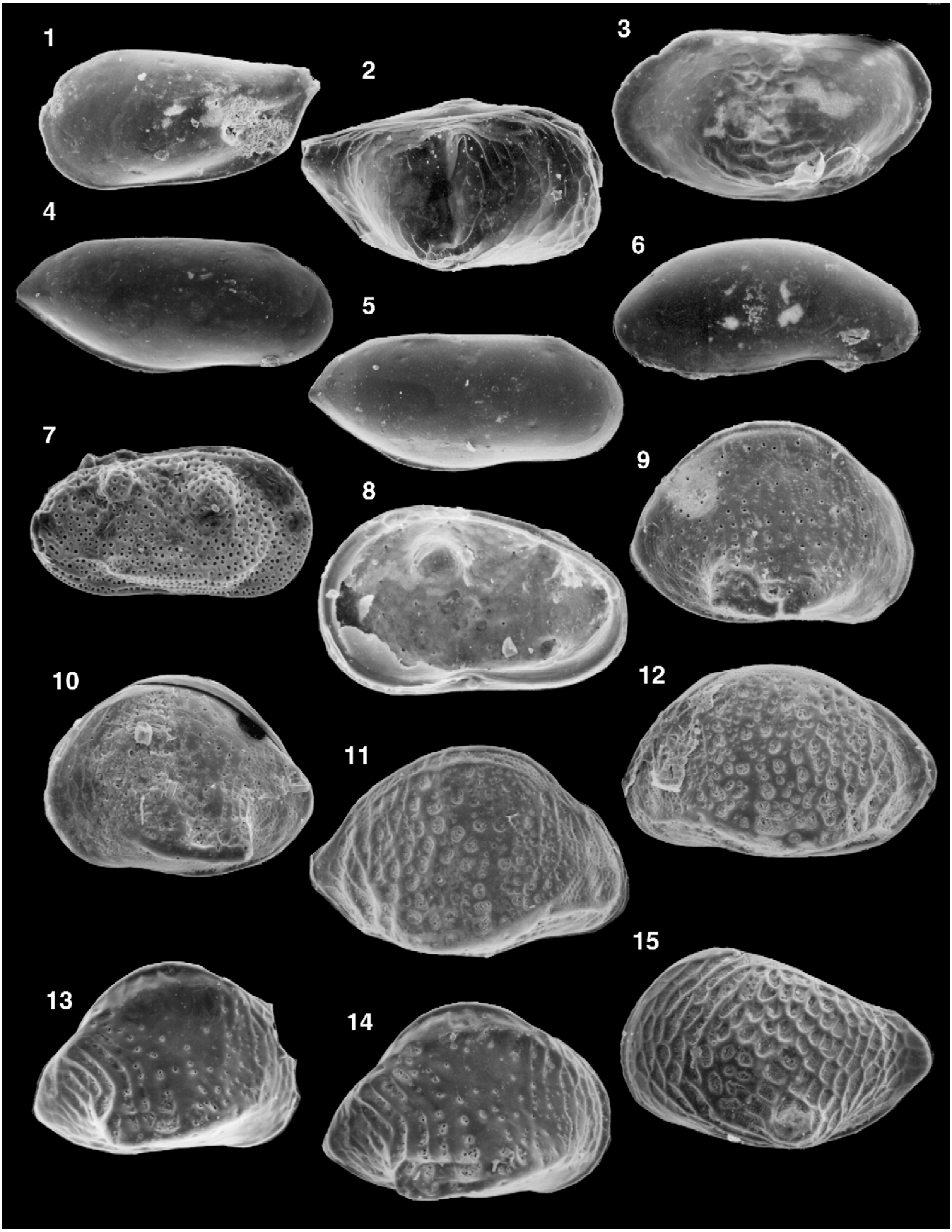


Fig. 10. Relative abundance of euryhaline (A) and brackishwater together with freshwater (B) ostracod species in coretop samples from the eastern Laptev Sea. Ostracodal assemblages in the eastern Laptev Sea (B). Station numbers according to numerical order of stations given in Tables 1 and 4. Dotted line in A shows the average position of fast ice margin (after Dmitrenko et al., 1998). Dotted line in B shows tentative boundaries between ostracodal assemblages.


1
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15

ostracod samples from the deeper part of the Kara Sea, collected during the U.S. Coast Guard Northwind cruises in 1963 and 1965, are listed in the Modern Arctic Podocopid Ostracode Database (MAPOD, Cronin et al., 1991). Samples were obtained from water depths between 203 and 640 m, but most of them were barren of ostracods. In four samples from 223 to 421 m water depth forty-four ostracod species were found. Only sixteen of these species were also found in our samples. These are mainly species from relatively deep locations (*Pseudocythere caudata*, *Bythocythere constricta*, *Cytheropteron arcuatum*, *C. inflatum*, *C. tumefactum*, *Argilloecia conoidea*). We consider them to be typical representatives of the North Atlantic ostracod fauna (Stepanova et al., 2003, 2004; Stepanova, 2006). Several shallow-water and one brackish-water species were also listed in the MAPOD (Cronin et al., 1991), such as *Sarsicytheridea bradii*, *H. sorbyana*, *C. macchesneyi*, which we consider ice-rafted, as they usually do not live at such depths (Stepanova et al., 2003, 2004; Stepanova, 2006). In the work of Jørgensen et al. (1999), samples from the estuarine and near-shore locations of the southwestern Kara Sea were studied. Among the species the authors list *Philomedes globosa globosa* — the synonym of the *Philomedes brenda*, found in our samples from water depths of 68 and 88 m. The latter is the only myodocopid species among 8 identified by Chavtur (2001). He also listed 3 species of the family Polycopidae, which we included in *Polycope* spp. Schornikov (2001) identified 6 podocopid species, five of these species were also found in our samples. These are typical neritic species *Acanthocythereis dunelmensis*, *Rabilimis mirabilis*, *S. bradii*, *S. punctillata, H. sorbyana*. In a study devoted to the investigation of the Holocene bottom water hydrography Simstich et al. (2004) studied stable isotopes in valves of four ostracod species: *S. punctillata*, *H. sorbyana*, *P. pseudopunctillata* and *C. macchesneyi*. Specimens were picked from 52 samples obtained during four summer expeditions to the Kara Sea between 1997 and 2001. Many of these samples are included in this work.

Ostracodal abundance is the lowest in the southern estuarine parts of the Ob' and Yenisei rivers (Fig. 5). The highest abundance is found in the samples collected close to the fast ice margin (for its position see Fig. 7A) thus probably reflecting the relatively high productivity in the ice-marginal zone close to the polynya. In the samples with the highest total abundance the percentage of dead valves is relatively low, ranging from 5 to 16%. Taxonomic diversity increases in offshore direction from 1–5 species per sample in the estuaries to 13–16 in mid-shelf zone. In the deeper zone it becomes lower and averages 2–7 species per sample.

4.1.2. Ecological groups and assemblage composition

The analysis of the modern distribution pattern of ostracods in the eastern Kara Sea is based on the combination of the data on spatial variations in relative abundances of species belonging to different ecological groups (Figs. 6 and 7) and the groupings of samples shown by the cluster dendrogram (Fig. 8).

The deep-living marine species (Table 2) have their maximum occurrences (up to 50%) in the outer shelf and in the St. Anna trough below 50 m water depth (Fig. 6A). Rare occurences of these species on the shallow shelf might be the result of the transportation of dead valves with the reversal bottom currents characteristic of submarine paleo-river channels in this area (Dmitrenko et al., 2001; Harms et al., 2003). Otherwise, these currents may maintain constant high-salinity bottom water conditions for deep-living species. Most of the findings of these species are indeed restricted to the Ob' and Yenisei submarine paleovalleys.

Shallow-water marine species (Table 2; Fig. 6B) constitute the taxonomically most diverse and abundant group on the Kara Sea shelf. They are found all over the study area except the inner estuaries, where bottom water salinity is less than 14 (Fig. 3B). The finding of a single dead valve of *Semicytherura complanata* at station BP00-15 ("26" in Fig. 6B) is probably a result of post-mortem transportation in this hydronamically active estuarine environment.

Euryhaline species (*P. pseudopunctillata*, *H. sorbyana*, *H. fascis*) form the second most abundant group of species in the Kara Sea (Fig. 7A). Although they occur at the majority of stations, they dominate the outer estuaries and

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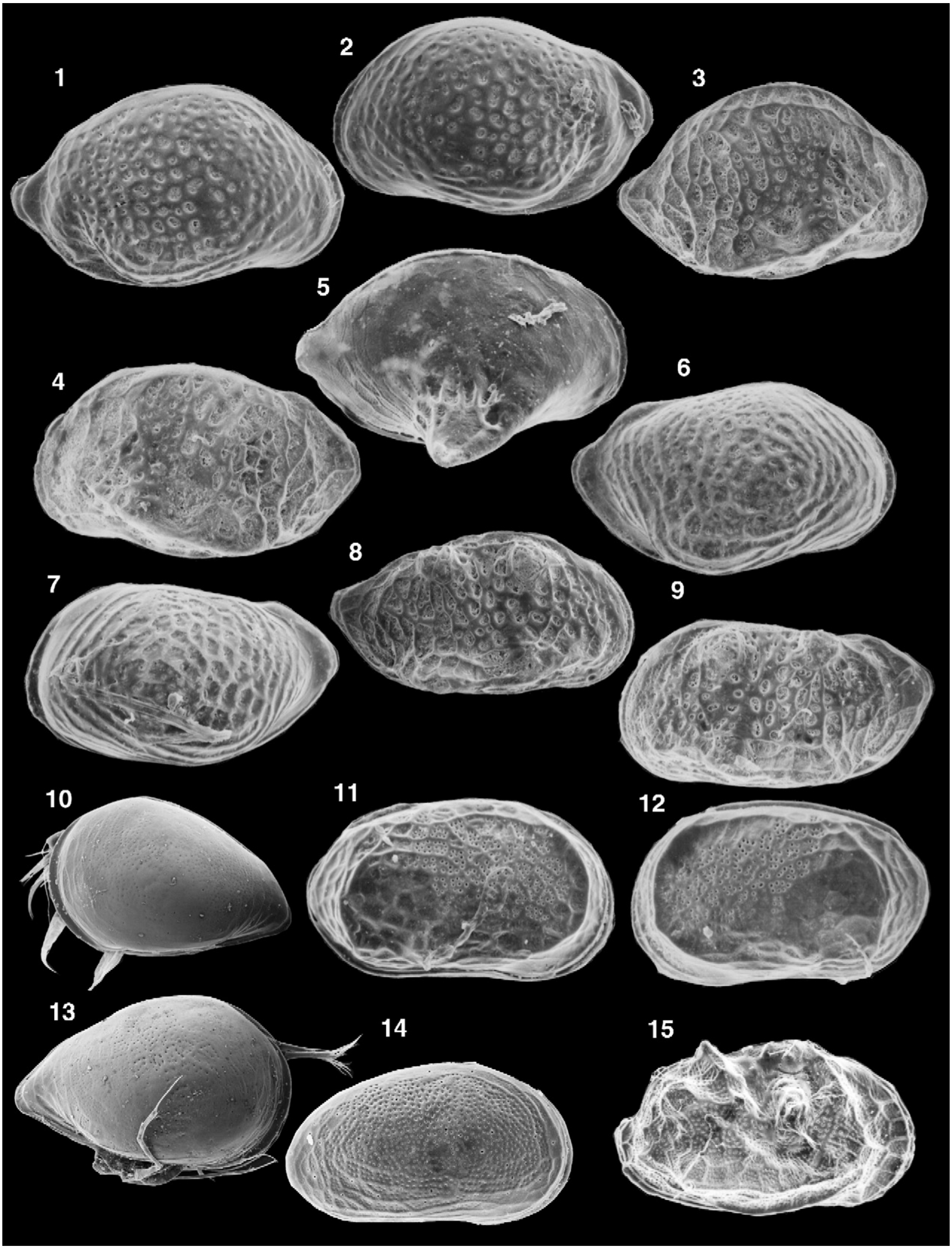
Plate I. Fig. 1. *Pseudocythere caudata* Sars, 1866: left valve external view, x95; station BP00-29. Fig. 2. *Bythocythere constricta* Sars, 1926: juvenile carapace seen from the right side, x135; station BP01-46. Fig. 3. *Bythocythere* sp.1: left valve external view, x155; station BP00-31. Figs. 4, 5. *Jonesia acuminata* (Sars, 1866): 4 — right valve external view, x50; station BP99-01; 5 — right valve external view, x55; station BP00-09. Fig. 6. *Sclerochilus* sp.1: right valve external view, x70; station BP00-28. Figs. 7, 8. *Cluthia cluthae* (Brady, Crosskey and Robertson, 1874): 7 — right valve external view, x155; station BP00-09; 8 — right valve internal view, x180; station BP00-09. Figs. 9, 10. *Cytheropteron arcuatum* Brady, Crosskey and Robertson, 1874: 9 — right valve external view, x130; station BP00-27; 10 — left valve external view, x145; station BP00-29. Figs. 11, 12. *Cytheropteron champlainum* Cronin, 1981: 11 — right valve external view, x115; station BP00-09; 12 — left valve external view, x110; station BP99-12. Figs. 13, 14. *Cytheropteron elaeni* Cronin, 1989: 13 — right valve external view, x150; station BP00-09; 14 — right valve external view, x130; station BP00-23. Fig. 15. *Cytheropteron montrosiense* Brady, Crosskey and Robertson, 1874: left valve external view, x150; station BP99-13.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adjacent inner shelf zone within the limits of the fast-ice cover distribution (Fig. 7A). Another relative abundance peak of euryhaline species correlates approximately with the occurrence of deep-living species on the outer shelf and in the St. Anna trough. This might be a result of ice-rafting from the coastal zone, where these species have their maximum occurrence (Stepanova et al., 2003).

Brackishwater species (*C. macchesneyi* and *P. cumuloidea*) are clearly restricted to the outer Ob' and Yenisei estuaries (Fig. 7B). This is the zone of the salinity front, where bottom salinity sharply increases from approximately 10 to 26 (Fig. 3B).

Freshwater species *Candona harmsworthi*, *Candona* sp. juv., *Cytherissa lacustris* occur at three stations within the freshwater influenced environment of the inner Yenisei and Ob' estuaries where they are the only ecological group present with an admixture (15%) of a euryhaline species *H. sorbyana* at one station (BP01-14) (Fig. 7B).

The dendrogram obtained for the Kara Sea samples (Fig. 8) consists of four clusters. Cluster I is solely comprised of samples from water depths exceeding 50 m, and most stations included in this cluster are located deeper than 120 m. These samples are characterized by the presence of relatively deep-living marine species: *A. conoidea* (up to 18%), *C. arcuatum* (up to 18%), *Cytheropteron tumefactum* (up to 36%), *Krithe glacialis* (up to 20%).

Cluster II includes samples with different ecological groups of species (freshwater, brackishwater, euryhaline and shallow-water marine) from the estuarine parts of the Ob' and Yenisei rivers and adjacent locations. Samples from this area are taxonomically poor due to low salinities, and mainly contain representatives of one to three species. Sample BP01-61 from 101 m water depth is also included in this cluster, since it contains valves of only one shallow-water marine species.

Cluster III unites samples from the entire study area and largely consists of shallow-water marine species with a considerable portion of euryhaline species, namely *P. pseudopunctillata* (up to 77%) and *H. sorbyana* (up to 73%).

Cluster IV characterizes a shallow-water marine assemblage with an almost complete absence of euryhaline species. Dominant taxa from these samples combined into this cluster are *S. bradii* (up to 57%), *Cluthia cluthae* (up to 35%), *Cytheropteron elaeni* (up to 41%), *C. sulense* (up to 26%), *A. dunelmensis* (up to 23%).

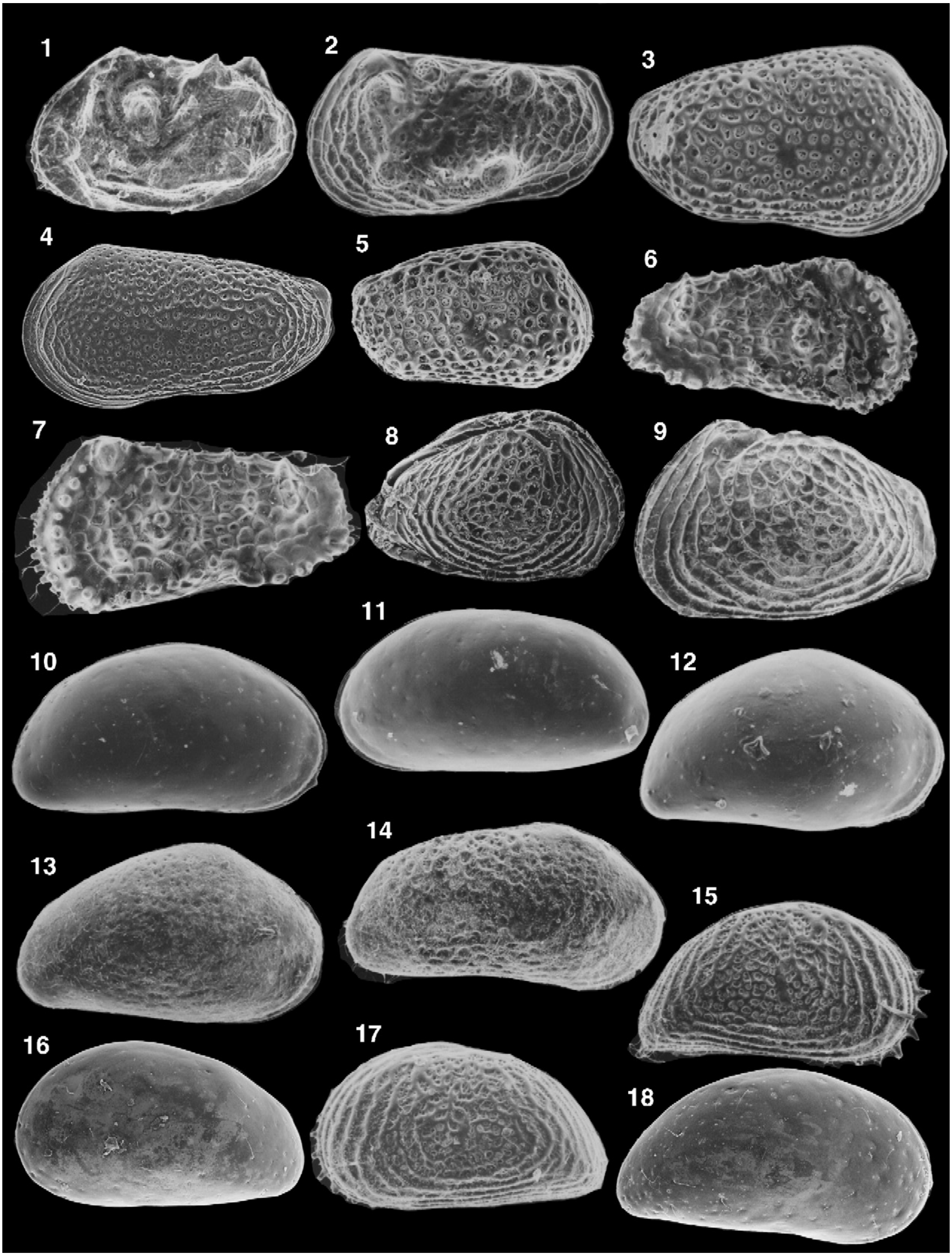
Summarizing the observed distribution patterns of ostracods in the eastern Kara Sea we can tentatively establish four assemblages replacing each other in offshore direction (Fig. 7B): (1) a freshwater assemblage of the inner estuaries; (2) a brackishwater assemblage of the outer estuaries; (3) a euryhaline–marine assemblage of the inner shelf (down to approximately 25 m water depth); (4) a marine assemblage for the remaining part of the sea. The latter could be subdivided into three sub-assemblages: (4a) the marine sub-assemblage with considerable proportions of euryhaline species occupying mid-shelf depths along the Taimyr coast; (4b) the mid-shelf sub-assemblage dominated by shallow-water marine species with insignificant amounts of euryhaline species; and (4c) the marine sub-assemblage of the outer shelf and St. Anna trough enriched in deep-living species.

4.2. Laptev Sea

4.2.1. Taxonomic composition and abundance pattern

Our previous studies of the Laptev Sea Ostracoda from surface samples revealed a strong relationship between water depth and salinity and distribution of the assemblages on the shelf (Stepanova et al., 2003; Stepanova, 2006). In the last two years new coretop samples were obtained from the eastern inner- and mid-shelf area and from coastal thermokarst lagoons (Table 4). These data are combined with the existing database on the Laptev Sea Ostracoda. In total, 37 species were identified in the eastern Laptev Sea (Table 4). Ostracod abundance in the eastern Laptev Sea is not high with the lowest values observed at mid-shelf depths (Table 1). Samples from this part of the shelf are largely represented by living ostracods.

Plate II. Figs. 1, 2. *Cytheropteron occultum* Whatley and Masson, 1979: 1 — right valve external view, x95; station BP99-17; 2 — left valve external view, x90; station BP99-17. Figs. 3, 4. *Cytheropteron nodosoalatum* Neale and Howe, 1975: 3 — right valve external view, x95; station BP99-02; 4 — left valve external view, x100; station BP99-02. Fig. 5. *Cytheropteron paralatissimum* Swain, 1963: left valve external view, x110; station BP00-31. Figs. 6, 7. *Cytheropteron sulense* Lev, 1972: 6 — right valve external view, x105; station BP99-17; 7 — left valve external view, x105; station BP99-31. Figs. 8, 9. *Cytheropteron suzdalskyi* Lev, 1972: 8 — right valve external view, x100; station BP99-25; 9 — left valve external view, x110; station BP00-23. Figs. 10, 13. *Cytheropteron tumefactum*, Lev 1972: 10— carapace seen from the left side, x135; station BP01-56; 13— carapace seen from the right side, x135; station BP01-48. Figs. 11, 12. *Semicytherura complanata* (Brady, Crosskey and Robertson, 1874): 11 — right valve external view, x155; station BP00-09; 12 — left valve external view, x155; station BP00-29. Fig. 14. *Semicytherura* sp.1 right valve external view, x100; station BP00-22.Fig. 15. *Palmenella limicola* (Norman, 1865): right valve external view, x85; station BP00-07.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For the first time, the freshwater species *C. harmsworthi*, *Candona* sp.juv., *Limnocythere* sp. 1, 2, *Cypria* sp. were recorded in coretop samples from the coastal thermokarst lagoons (Table 4). Most ostracods from the thermokarst lagoons were collected alive (besides *Limnocythere* specimens in Pestsovaya lagoon), although during the time of sampling in spring 2005 the thick ice cover in Uomullyakhskaya lagoon was lying directly on the sediment, and in Pestsovaya lagoon a 1.8-m thick ice was underlain by a 30-cm thick water layer with salinity as high as 19.

4.2.2. Ecological groups and assemblage composition

The deep-living marine species (Table 2) are most abundant on the upper continental slope below 70–80 m water depth, where they reach up to 74% (Fig. 9A). They are occasionally present at several sites on the shelf, primarily in the Lena paleovalley. This implies the possibility of their introduction and/or transportation due to reversal bottom currents, also seen in the Kara Sea. Most of these finds, especially at the most shallow-water localities, are valves of *Polycope* spp. (Table 4).

Shallow-water marine species (Table 2) form the taxonomically most diverse and abundant ecological group of ostracods in the eastern Laptev Sea (Fig. 9B). Although present at most locations, they reach highest relative abundances (50–100%) in the mid-shelf zone.

Euryhaline species (Table 2) predominate on the inner shelf, in the reduced salinity zone (salinity range 18–26) beneath the fast ice cover (Fig. 10A). Their relative abundance considerably decreases offshore, but at some localities on the outer shelf and upper continental slope they are also abundant, for instance, at station PS51/114–13, where they reach 55%.

Only one brackishwater species *C. macchesneyi* has been reported from the Laptev Sea. It is occasionally found in coretop samples from the inner shelf zone close to the Lena River delta, where usually comprises less than 10% (Fig. 10B).

Freshwater species occur in the coastal thermokarst lagoons, but have not been found in the Laptev Sea sediments (Fig. 10B).

Based on the distribution of ecological groups and clusters (Stepanova et al., 2003; Stepanova, 2006) we distinguish three ostracodal assemblages in the eastern Laptev Sea (Fig. 10B). The boundaries between assemblages are less distinct than in the Kara Sea, since the number of studied sites is half less, and the sites are spatially restricted to several small areas (Fig. 2). For the established assemblages we use the same numbering as in the Kara Sea (Fig. 7B): (1) a freshwater assemblage of the coastal thermokarst lagoons; (3) a euryhaline–marine assemblage of the inner shelf (down to 25–30 m water depth) with admixture of brackishwater elements; (4) a marine assemblage, which is subdivided into the mid-shelf assemblage (4b) dominated by shallow-water marine species with insignificant amount of euryhaline species and the marine assemblage (4c) of the outer shelf and upper continental slope with considerable portion of deep-living species.

5. Discussion

5.1. Taxonomic composition of recent Ostracoda from the Kara and Laptev seas

The total list of ostracod species from the Kara Sea based on our samples and published data (Elofson, 1941; Chavtur, 1983, 2001; Cronin et al., 1991; Jørgensen et al., 1999; Schornikov, 2001; Simstich et al., 2004) consists of 81 species, including four freshwater species from the inner estuaries (Table 2). The total list of ostracod species from the Laptev Sea includes 91 species from the shelf and upper continental slope (summarized in Stepanova, 2006), and five freshwater species from coastal thermokarst lagoons. Comparison of the recent ostracod associations of the two seas using the Jaccard coefficient (Jaccard, 1912) reveals that the similarity value is low − 30% (freshwater species are not considered in the calculations). This is largely dependent on numerous synonym species names listed in the publications which we are unable to revise due to the absence of illustrations. However, if we

Plate III. Fig. 1. *Palmenella limicola* (Norman, 1865): left valve external view, x80; station BP00-07. Fig. 2. *Roundstonia globulifera* (Brady, 1868): left valve external view, x135; station BP00-23. Figs. 3, 4. *Cytheromorpha macchesneyi* (Brady and Crosskey, 1871): 3 — right valve external view, x120; station BP00-08; 4 — left valve external view, x125; station BP00-22. Fig. 5. *Pteroloxa cumuloidea* Swain, 1963: carapace seen from the right side, x156; station BP01-52. Figs. 6, 7. *Acanthocythereis dunelmensis* (Norman, 1865): 6 — right valve external view, x55; station BP00-23; 7 — left valve external view, x55; station BP00-23. Figs. 8, 9. *Rabilimis mirabilis* (Brady, 1868): 8 — carapace seen from the right side, x97; station BP01-52; 9 — left valve external view, x55; station BP00-28. Figs. 10–12. *Sarsicytheridea bradii* (Norman, 1864): 10 — right valve external view, x75; station BP00-29; 11 — left valve external view, x65; BP00-09; 12 — right juvenile valve external view, x90; station BP00-09. Figs. 13, 14. *Sarsicytheridea punctillata* (Brady, 1864): 13 — right juvenile valve external view, x85; station BP00-28; 14 — right valve external view, x70; station BP00-28. Figs. 15, 17. *Heterocyprideis sorbyana* (Jones, 1857): 15 — right valve external view, x65; station BP00-28; 17 — left valve external view, x70; station BP00-28. Figs. 16, 18. *Paracyprideis pseudopunctillata* Swain, 1963: 16 — left valve external view, x75; station BP00-22; 18 — left valve external view, x70; station BP00-22.

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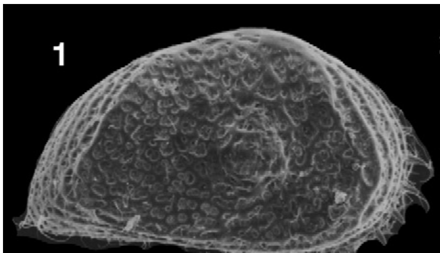

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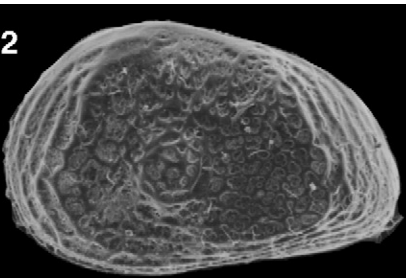

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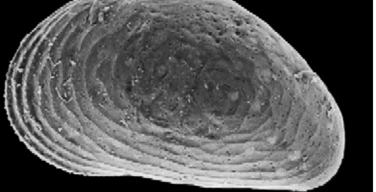

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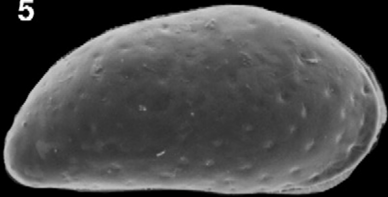

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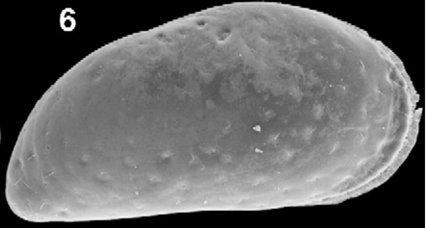

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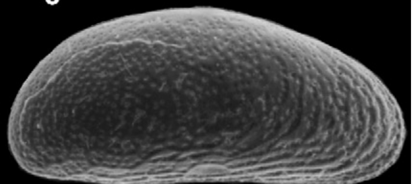

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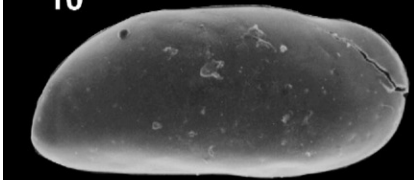

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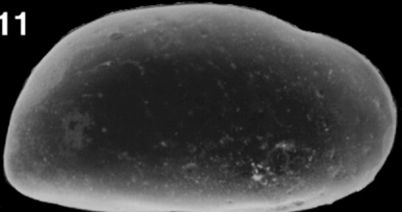

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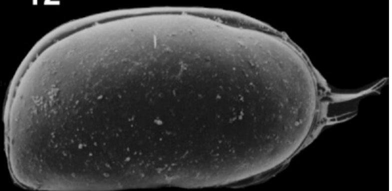

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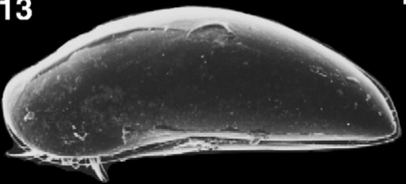

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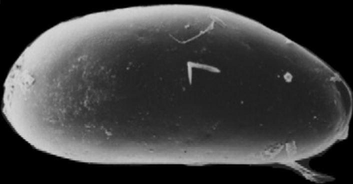

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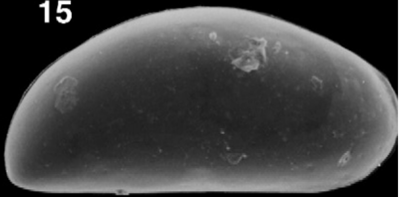

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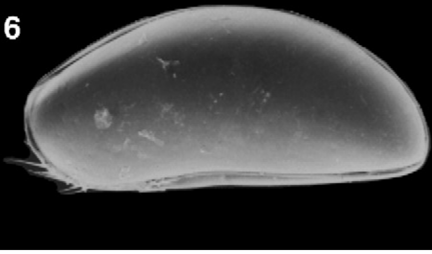

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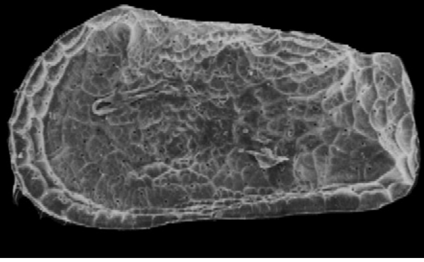

compare taxonomic compositions of ostracods from our samples collected in the eastern, river-affected parts of the seas, the similarity becomes considerably higher (52%).

5.2. Ostracodal assemblages in the river-affected eastern parts of the Kara and Laptev seas

The most evident feature in the distribution of ostracods in the eastern Kara and Laptev seas is their strong dependence on the bottom water salinity. Our data clearly demonstrate that there is an offshore succession of ostracodal assemblages following the salinity increase and decreasing river runoff influence (Figs. 7B and 10B).

The freshwater assemblage in the Kara Sea (number 1 in Fig. 7B) occupies the inner Ob' and Yenisei estuaries, where the average summer bottom salinity is less than 2 (Fig. 3B). Salinity measurements at the stations with freshwater ostracods performed at the time of sampling (August) ranged from 0.05 to nearly 14 (BP01-14) (Table 1). At the latter station not only freshwater ostracods (85% relative abundance), but also a euryhaline species *H. sorbyana* (15%) were determined. The salinity increase at this station might be a result of upstream seawater advection in the bottom water layer.

In the Laptev Sea, the freshwater assemblage occurs only in surface sediments of coastal thermokarst lagoons (number 1 in Fig. 10B). As noted before, in one of these lagoons (Uomullyakhskaya) ice was lying directly on the sediment, and all ostracods collected there were alive. This implies that freshwater ostracods of *Candona* and *Limnocythere* genera found there are able to survive the freeze-through conditions during winter. In Pestsovaya lagoon, bottom water salinity measured in spring 2005 was as high as 19. This is a result of ice formation. Water salinity in summer was not measured, but it is supposed that the water was almost fresh. In summer, freshwater species inhabit the lagoons. In winter, they either freeze into ice (or bottom ground as in Uomullyakhskaya lagoon) and are preserved in anabiosis, or die and decay very slowly due to low temperatures. That is why the collected freshwater ostracods, besides *Limnocythere* specimens from Pestsovaya lagoon, are brightly stained with Rose Bengal, although they obviously can not survive salinity as high as 19.

No specimens of freshwater ostracods were found in our samples from either the Kara or Laptev seas, unlike, for instance, the Beaufort Sea where freshwater species are common in shelf sediments (McDougall et al., 1986). Valves of freshwater species seem to be not transported to the sea by rivers because of the prevailing upstream flow of seawater at the bottom compensating the strong river runoff outflow. Specimens of freshwater ostracods from terrestrial lacustrine and lagoonal deposits, which are subject to abrasion, are probably largely destroyed by waves and thus were not accumulated in shelf sediments.

We only distinguish a separate brackishwater ostracodal assemblage in the Kara Sea (number 2 in Fig. 7B). It occupies the outer estuaries of the Ob' and Yenisei rivers, where brackishwater species *C. macchesneyi* and *P. cumuloidea* reach high relative abundances (up to 100%). The outer boundary of the brackishwater assemblage generally coincides with the average position of the 26 bottom-water isohaline in summer (Fig. 3B), although point salinity measurements at the studied sites range from 2 to 27 in the Ob' estuary and from 14 to 30 in the Yenisei estuary (Table 1). In the Laptev Sea we have no samples from the outer estuaries of river mouths and channels of the Lena delta. In the shelf sediments of the Laptev Sea only one brackishwater species *C. macchesneyi* is recorded. Its rare findings mainly originate from the near-shore zone bounded by the average position of the 26 bottom-water isohaline in summer (Fig. 4).

The brackishwater assemblage of the Kara Sea inhabits the zone of strongest seasonal contrasts in both salinity and temperature primarily related to fluctuations in river discharge (Bauch et al., 2003; Simstich et al., 2005a). Besides brackishwater species, euryhaline and shallow-water marine ostracods also occur in this assemblage thus reflecting the complicated interactions between riverine

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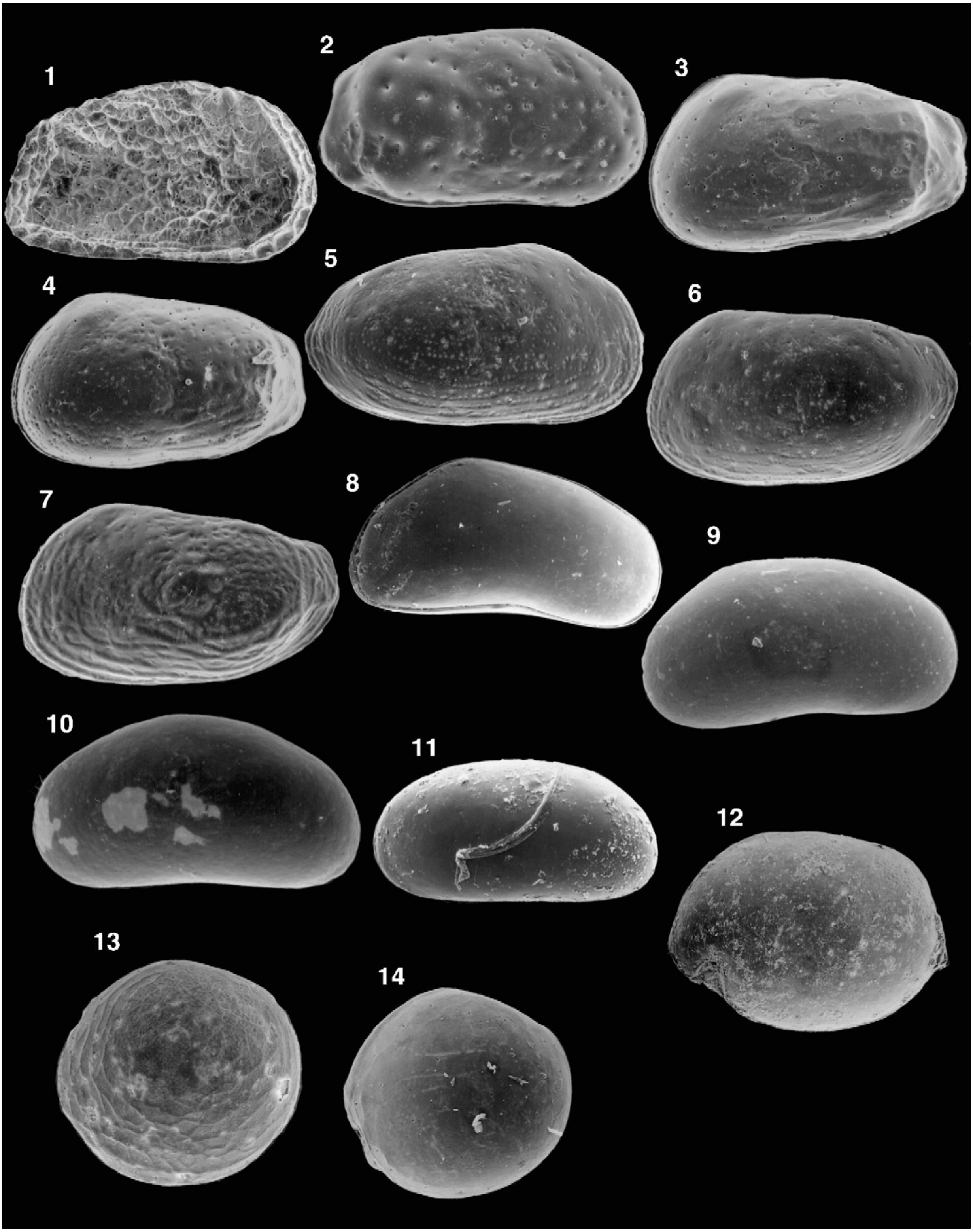
Plate IV. Figs. 1, 2. *Heterocyprideis fascis* (Brady and Norman, 1889): 1 — right valve external view, x65; station BP00-29; 2 — left valve external view, x65; station BP99-31. Fig. 3. *Eucythere argus* (Sars, 1866): left valve external view, x150; station BP00-22. Fig. 4. *Paracyprideis pseudopunctillata* Swain, 1963: left valve external view, x70; BP00-22. Figs. 5,6. *Sarsicytheridea macrolaminata*? Elofson, 1941: 5 — right valve external view, x80; BP00-09; 6 — right valve external view, x80; BP99-01. Figs. 7, 8. *Cytherissa lacustris* Sars, 1866: 7 — left valve external view, x70; BP01-73; 8 — right valve internal view, x70; BP01-73. Fig. 9. *Pontocythere* sp.1: left valve external view, x95; BP99-21. Figs. 10–12. *Krithe glacialis* Brady, Crosskey and Robertson, 1874: 10 — male right valve external view, x65; BP00-08; 11 — female right valve external view, x80; BP00-05; 12 — juvenile carapace seen from the right side, x60; BP01-56. Fig. 13. *Argilloecia conoidea* Sars, 1923: carapace seen from the left side, x90; BP01-56. Fig. 14. *Argilloecia cylindrica* Sars, 1923: carapace seen from the right side, x100; BP01-56. Figs. 15, 16. *Argilloecia* sp.1: 15 — right valve external view, x110; BP99-39; 16 — carapace seen from the left side, x95; BP00-08. Fig. 17. *Elofsonella concinna* (Jones, 1857): left valve external view, x65; BP00-31.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and marine waters in the outer estuaries. The brackish-water assemblage coincides with the inner part of the so-called "marginal filter" zone (its location is shown on the insert in Fig. 7B). Here, at the salinity front (Fig. 3B), most of the riverine suspended particulate and organic matter is accumulated, as is demonstrated by decreasing water depths compared to the inner estuarine zone (20–25 vs. 15 m) due to high sedimentation rates and considerable thickness of Holocene sediments (Dittmers et al., 2003; Stein et al., 2004). Freshwater diatoms are largely trapped in this zone also (Polyakova and Stein, 2004). However, high sedimentation rates reduce the biological productivity at the bottom of the estuaries (Vedernikov et al., 1995). Correspondingly, the abundance of ostracods in the outer estuaries is low (Fig. 5).

In the inner shelf zone of the Kara and Laptev seas, northward from the Ob' and Yenisei estuaries and Lena delta, a euryhaline–marine assemblage occurs down to water depths of 20–30 m (number 3 in Figs. 7B and 10B). It consists of brackishwater, euryhaline and shallow-water marine ostracods with the predominance of the two euryhaline species *P. pseudopunctillata* and *H. sorbyana*, which are tolerant to considerable seasonal changes in highly variable river-affected environments. Average summer bottom-water salinity in the area occupied by this assemblage ranges between 26 and 32 (Figs. 3B and 4B). Being largely located beyond the marginal filter zone (Fig. 7B) in the region with considerably reduced sedimentation rates and water turbidity but still high supply of nutrients with riverine waters, this zone is characterized by high productivity (Vedernikov et al., 1995). Thus, the maximum total abundance of ostracods is recorded in this area at a certain distance from the estuaries and delta (Table 1, Fig. 5). The inner shelf assemblage dominated by euryhaline species generally occurs within the limits of the fast ice. During autumn storms and the freeze-up period, parts of the bottom sediment in the coastal region are resuspended, and considerable amounts of sediment particles (including ostracods) are incorporated into the newly formed ice and transported to the continental slope and the Arctic Ocean (Wegner, 2003). This mechanism may explain the observed distribution pattern of euryhaline species which are dominant in the inner shelf assemblage, but demonstrate another increase in abundance in the distant ice-melting zone at the shelf break and upper continental slope (Figs. 7A and 10A; Stepanova et al., 2003). For instance, the ostracodal assemblage from the deepest studied station in the Kara Sea (295 m) consists of 55% deep-water taxa and 45% of euryhaline species *H. sorbyana*.

The marine assemblage occupies the largest part of the Kara and Laptev Sea shelves and upper continental slope, where shallow-marine species are dominant (number 4 in Figs. 7B and 10B). Bottom environmental conditions are relatively stable in these parts of the seas, and the average summer bottom-water salinity increases with water depth from 32 to >34 (Figs. 3B and 4B). Besides shallow-marine taxa, euryhaline and deep-living marine species are important components of this assemblage, and spatial differences in their relative abundances allow us to distinguish several sub-assemblages (Fig. 10B). In the mid-shelf depths along the Taimyr coast, the 4a assemblage with a considerable proportion of euryhaline species generally follows the direction of riverine water input and mirrors the extent of the fast ice cover. The taxonomically diverse 4b assemblage with the maximum share of shallow-water marine species occupies the mid-shelf areas in the central parts of both seas. The relatively low total abundances of ostracods here might be due to resuspension of ostracods in paleovalleys by reversal currents and transportation onto the inner shelf (Dmitrenko et al., 2001; Wegner, 2003). On the outer shelf and upper continental slope the 4c assemblage occurs characterized by the presence of relatively deep-living species typical for the North Atlantic and Arctic oceans. In the Kara and Laptev seas, these species are mainly related to the waters of Atlantic origin.

6. Conclusions

We have thoroughly investigated recent Ostracoda from the eastern Kara Sea firstly to supplement the taxonomical database of ostracods from this area and, secondly, to understand the modern ecology of ostracods in the strongly river-runoff affected arctic marginal seas, thus providing a reliable basis for paleoenvironmental

Plate V. Fig. 1. *Elofsonella concinna* (Jones, 1857): right valve external view, x65; BP00-09. Figs. 2–4. *Normanicythere leioderma* (Norman, 1869): 2 — right valve external view, x65; BP00-29; 3 — left juvenile valve external view, x80; BP00-28; 4 — left juvenile valve external view, x85; BP00-28. Figs. 5–7. *Cytheretta teshekpukensis* Swain, 1963: 5 — right valve external view, x65; BP99-21; 6 — left valve external view, x55; BP99-21; 7 — left juvenile valve external view, x120; BP99-21. Fig. 8. *Candona harmsworthi* Scott, 1899: carapace seen from the right side, x110; BP01-73. Figs. 9, 10. *Candona* sp. juv. 1: 9 — carapace seen from the right side, x70; BP00-20; 10 — right valve external view, x100; BP00-20. Fig. 11. *Candona* sp. juv. 2: carapace lateral view, x70; BP01-73. Fig. 12. *Philomedes brenda* (Baird, 1850). 2: carapace seen from the left side, x40; BP01-31. Figs. 13, 14. *Polycope* spp.: 13 — carapace, x110; BP99-28; 14 — carapace, x105; BP01-46.

reconstructions. The latter task demanded comparison of the ostracodal associations from the eastern Kara and Laptev seas in order to establish a distribution pattern of various ecological groups in relation to environmental parameters, primarily, the bottom water salinity.

As a result, the existing database on the composition and distribution of recent ostracods from the eastern Kara and Laptev seas has been considerably enlarged. In the eastern Kara Sea, a total of forty-five species were identified, twenty-seven of them were reported for this region for the first time. A strong similarity in distribution pattern of the ecological groups of ostracods and their assemblages revealed between the two seas reflects bottom water salinity changes and river runoff influence. Four major assemblages are recognized which gradually replace each other in offshore direction. The freshwater assemblage (*C. lacustris*, *C. harmsworthi*, *Candona* spp., *Limnocythere* spp., *Cypria* sp.) is found in the inner estuaries of the Ob' and Yenisei with the average summer bottom water salinity less than 2 and in thermokarst lagoons on the southern Laptev Sea coast with high winter salinity caused by ice formation. The brackishwater assemblage dominated by *C. macchesneyi* and *P. cumuloidea* has been distinguished in the Ob' and Yenisei outer estuaries within the average summer bottom water salinity range of 2–26. This assemblage encompasses the river–sea salinity front, where the bottom water salinity sharply increases from 10 to 26. The taxonomically diverse mixed euryhaline–marine assemblage dominated by euryhaline species *H. sorbyana* and *P. pseudopunctillata* occupies the inner shelf zone northward from river mouths down to the depths of 20–30 m, where the average summer bottom water salinity grows from 26 to 32. In the remaining part of the seas, where riverine influence is negligible and the average summer bottom water salinity is above 32, the taxonomically diverse marine assemblage occurs. This assemblage is dominated by various shallow-water marine species (*S. bradii*, *C. cluthae*, *C. elaeni*, *C. sulense*, *A. dunelmensis*, *S. complanata*). In the deepest locations in the St. Anna trough (water depths more than 80–100 m) deep-living species (*C. tumefactum*, *C. arcuatum*, *K. glacialis*, *A. conoidea*, *Polycope* spp.) become abundant, but also euryhaline species dominating the inner shelf assemblage show a second abundance peak. We consider ice-rafting to be the main agent distributing ostracods from the freshened near-shore zone, where they are entrained into the fast ice during freeze-up in autumn, to distant offshore regions. It seems unlikely that benthic organisms are transported northward by brackishwater inflows along the paleovalleys as supposed by Petryashov et al. (1999), since the paleovalleys are pathways of reversal bottom water currents (Dmitrenko et al., 2001), which resuspend sediment material and transport it onto the inner shelf (Wegner, 2003). The observed second abundance peak of euryhaline species in distal locations could indicate that the time when fast ice blocks reach this area coincides with maximum summer warming up, when ice melts and releases sediment particles and ostracods entrained on the inner shelf.

Acknowledgements

This study is part of the joint Russian–German research projects “Siberian River Run-Off” (SIRRO) and “Laptev Sea System”. We thank E. Abramova (Lena Delta Reserve) and V. Tumskoi (MSU) for collecting sediment samples from the Laptev Sea shelf and coastal lagoons. We acknowledge the assistance of collaborators of the Otto Schmidt Laboratory for Polar and Marine Sciences (OSL) in sample processing and S. Kirillov (AARI) in interpreting oceanological data. We are grateful to colleagues — ostracodologists W. Briggs (NAMPO, Colorado) and E. Schornikov (IBM, Vladivostok) for the fruitful discussions and consultations in species identifications. We would also like to thank reviewers T.M. Cronin (BSGS) and I. Boomer (University of Birmingham) for their valuable comments and corrections. This research was supported by the BMBF and Russian Ministry for Education and Science (OSL, project OSL-05-31), Russian Foundation for Basic Research (project 05-05-64823), and INTAS (project 03-51-6682).

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