Report on Bivalve Mollusks from Beach Death Assemblages in Gangwon and Gyeongsangbuk Provinces, Korea (East Sea)

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ABSTRACT

Beach death assemblages of bivalve mollusks were studied with respect to their species composition in six localities along the eastern coast of Korea (Gangneung, Jumunjin, Daejin, Gallam, Jukbyeon, Hupo and Chooksan). In all, thirty-nine species belonging to 30 genera and 19 families were recorded, and species diversity between the sampling sites varied from 5 to 21. Biogeographical analysis showed that studied fauna has warm-water character with the predominance of subtropical and subtropical-lowboreal species and the presence of tropical-subtropical species (in total, 77 %), and only 23 % of mollusks found are cold-water and temperate species. The most abundant species were *Septifer virgatus* (Wiegmann, 1837), *Mytilus galloprovinciallis* Lamarck, 1819, *Gomphina melanaegis* Römer, 1861, *Ruditapes philippinarum* (Adams et Reeve, 1850), *Mactra chinensis* Philippi, 1847 and *Spisula sachalinensis* (Schrenck, 1862).

Keywords: Bivalvia, East Sea, Korea, Biogeography, Beach molluscan assemblages.

INTRODUCTION

Studies on beach molluscan thanatocoenoses death assemblages of empty shells are very common because results of such actuopaleontological researches can be used by paleontologists in taphonomic/ paleoecological reconstructions. Attention is mostly paid to the processes of transport, breakage, sorting, patterns of erosion, and left-right phenomena (Lever, 1958; Martinell and de Porta, 1982; Trewin and Welsh, 1972; Krommenhoek, 2000, and others). More integrative approach involves studies of taphonomic (preservational) variation of death assemblages (Kowalewski *et al.*, 1994). Examination of beach shell accumulations in relation to onshore and alongshore processes and to beach subfacies and physical sedimentary structures, formation of storm deposits and beach-shell dynamics are also important issues of sedimentological and taphonomic researches (Raymond and Stetson, 1932; Dörjes *et al.*, 1986; Frey and Dörjes, 1988a; b; Boyajian and Thayer, 1995). Marine biologists often document mass strandings of mollusks on the beaches after stormy weather, hurricanes and typhoons (Eggleston and Hickman, 1972; Rakov and Kucheryavenko, 1977; Kalashnikov, 1984).

Special faunal studies on beach thanatocoenoses are more rare though many regional molluscan surveys include beach collecting in order to make faunal lists as complete as possible. In neighboring Japan, there were several studies of such this carried out after strong typhoons (Nomura and Hatai, 1935; Horikoshi, 1960). A complex faunal-taphonomic approach was employed by Evseev (1976) and Lutaenko (1994a, b) when studying the beach shell accumulations in Vostok, Ussuriysky, Amursky and Possjet Bays in the northwestern East Sea (Japan Sea). In Korea, molluscan death assemblages were studied on

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macrotidal flats of the West (Yellow) Sea (Frey *et al.*, 1988; Hong and Park, 1998; Lutaenko, 2001a) with respect to their species composition, origin, spatial distribution and zonation, temporal changes, calcimass and size-frequency distribution of common species.

Bivalve mollusks of the Korean coast of the East Sea are still insufficiently studied despite remarkable progress in malacofaunal researches in Korea (Kwon *et al.*, 1993; 2001; Choe *et al.*, 1994; Rho *et al.*, 1998; Choi *et al.*, 2000b; Qi and Choe, 2000, and others). Knowledge of the precise geographical distributions of molluscan species in present-day Korean seas is of special importance as this would make it possible to elucidate complicated biogeographical structure of the East Sea with its cold and warm currents, upwellings and other oceanographic phenomena influencing zoogeography. This faunal report is based on the study of a collection of bivalve shells made in six areas along the coast of the Gangwon and Gyeongsangbuk Provinces by K.A. Lutaenko and S.-H. Shin during field-work in August 1997; the results of the study of benthic and beach samples from Yeongil Bay will be presented elsewhere.

REGIONAL SETTING AND COLLECTING SITES

The coastline of the Gangwon and Gyeongsangbuk Provinces (Republic of Korea) extending from north-west to south-east is nearly straight and monotonous and does not have large bays except for Yeongil-Bay. The coasts are mainly abrasional, but many accumulative areas can be found as well. The slopes of mountains approaching to the coast are quite steep, and cut by cliffs at their foots. The large rivers lack in this area; however, numerous streams flowing down to the coastal zone carry clastic material which provides a source of accumulative coastal forms. The accumulative areas are narrow beaches and low terraces filling the coastline concavities (Kaplin *et al.*, 1991). The continental shelf on the eastern coast of Korea is relatively narrow, no more than 32 km wide; in some areas, the shelf is almost absent, the depth of its break (140-150 m depth) is located on average at a distance of about 18 km from the coast.

According to Park (1988), the modern clastic sediments originating from coastal cliff-plain erosion and stream or riverine one seem to be restricted to the nearshore area (about 5 km wide). The rest of the shelf is covered with relict deposits. Along the shoreline, at depths less than 15 m, nearshore sand prisms, consisting of beach sand and/or seaward tining and fining wedge of nearshore sand, are well-developed. The sand prisms are transitional and grade into silty clay or clay which dominate in the inner shelf. In general, in the shelf area opposite Yeongil Bay, sand and gravelly sand along with silt are found at depths less than 100 m, and sandy silt is distributed in the zone lying deeper than the above-mentioned sand sediments (Park, 1988).

The oceanography of the East Sea is determined by both water dynamics and heat exchange between the sea and atmosphere. Warm saline surface waters derived from the Kuroshio Current enter the sea through the Korea Strait and flow northward in the eastern part of the East Sea. As a result, warm-water sector of the East Sea is formed and it includes the Warm East Korean Current which washes south-eastern Korea (Yurasov and Yarichin, 1991). In the northern sector of the sea, colder waters of the Liman (or Schrenck) Current and then the Primorskoye Current flow southward along the continental coast of Russia. Along the Korean coast, cold waters transform to the North Korean Current which brings hyper-ventilated, highly oxic and less saline waters. The latter cold current penetrates farther south than the North-South Korean border (Yurasov and Yarichin, 1991). Kim and Kim (1983) found that the coldwater mass off the Jugbyeon-Chooksan coast in summer belongs to the North Korean Cold Current (Water) and that is not an upwelled East Sea proper water mass. This current is strong in summer, and its southern limit is generally off Chuksan-Janggigab (i.e., Yeongil Bay) and occasionally more southern, off Gampo. Lee and Chung (1981) also reported that the North Korean Cold Current intrusion is strong and persistent in summer (August) with average velocity of 23.4 cm/sec near Jukbyon when the Tsushima Current is strong

Table 1. Sampling sites of bivalve mollusks in Gangwon and Gyeongsangbuk Provinces, Korea.

No. of region	Date	Position	Region
1	August 15, 1997	approx. 37°50'N 128°52'E	Gangwon Province, to the north of Gangneung, between Sachondan Cape and Yongok Stream mouth
2	August 17, 1997	37°34'25"N 129°07'12"E	Kangwon Province, near Taejin Village, Hanjindan Cape
3	August 18, 1997	37°16'47"N 129°19'26"E	Gangwon Province, near Gallam Village
4	August 18, 1997	37°03'23"N 129°25'47"E	Gyeongsangbuk Province, near Jukbyon Lighthouse
5	August 19-20, 1997	approx. 36°38'-40'N 129°26'-29'E	Gyeongsangbuk Province, around Hupo Bay
6	August 21, 1997	36°30'22"N 129°26'58"E	Gyeongsangbuk Province, near Chooksan Lighthouse

as well. However, no indication of the former current was detected in November. According to Kang and Jin (1984a), mean sea surface temperatures (SSTs) in the area selected for our study are between 16 and 15℃, and August SSTs are between 23 and 22℃ (Yurasov, 1977). In Uljin, at a depth of 10 m, maximum water temperature in August (1994-1996) reached 25.6℃, but generally it was 20℃ (Khim *et al.*, 1998). In the Gangwon Province (Ingu), annual water temperature of the geoduck clam's (*Panope japonica* = *P. abrupta*) fishing ground ranged from 5.6 to 17.5℃, with a maximum of 24.2℃ on the water surface (Lee *et al.*, 1998). North-south thermal front is formed parallel with the latitude of 36°N (An and Chung, 1982), i.e., around Pohang.

We collected bivalve molluscan shells at six sites around Gangneung, Jumunjin, Daejin, Gallam, Jukbyon, Hupo and Chooksan (Table 1). The area between Sachondan Cape and the Yongok Stream mouth (region 1) represents a wide sandy beach composed of coarse sand, with small rocks located at a distance of 100-150 m seaward. The similar sandy beach was also surveyed around Jumunjin (Fig. 1). Region 2 is located near Daejin Village (Hanjindan Cape) and is a rocky coast with a gravel beach (Fig. 2). Rocky coast with numerous islets and a coarse-grained beach was surveyed around Gallam Village (Fig. 3). Shores around Jukbyon (near the harbour), Hupo Bay and Chooksan are coarse- or, rarely, medium-grained sandy beaches. A majority of

Fig. 1. View of the coastal area around Jumunjin (sandy beach).

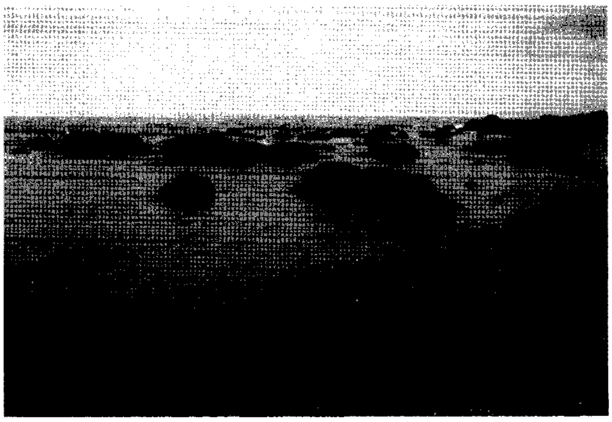

Fig. 2. *Protothaca euglypta* (Sowerby III, 1914). Region 4, outer and inner views of the same valve, length 26.8 mm.

Table 2. List of species of bivalve mollusks collected on beaches of Kangwon and Kyonsangbuk Provinces.

Species	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
Mytilus galloprovinciallis Lamarck, 1819	+	-	+	+	+	-
Mytilus coruscus Gould, 1861	+	-	+	-	+	-
Septifer virgatus (Wiegmann, 1837)	+	+	+	+	+	+
Septifer keenae Nomura, 1936	+	-	-	-	-	-
Modiolus agripetus (Iredale, 1939)	-	-	-	-	-	+
Modiolus kurilensis Bernard, 1983	+	-	+	-	+	-
Arca boucardi Jousseaume, 1894	+	-	+	+	-	+
Anadara kagoshimensis (Tokunaga, 1906)	-	-	-	+	-	-
Porterius dalli (Smith, 1885)	+	-	-	+	-	-
Glycymeris aspersa (Adams et Reeve, 1850)	-	-	-	+	+	-
Glycymeris cf. *rotunda* (Dunker, 1882)	+	+	-	-	-	-
Crassostrea gigas (Thunberg, 1793)	-	-	-	-	+	+
Crassostrea nipponica (Seki, 1934)	-	-	+	+	+	-
Chlamys swiftii (Bernardi, 1858)	+	-	-	-	-	-
Chlamys farreri (Jones et Preston, 1904)	+	-	-	-	-	-
Mizuhopecten yessoensis (Jay, 1857)	-	-	+	+	+	-
Anomia chinensis Philippi, 1849	+	-	-	-	-	-
Plicatula sp. Reeve, 1856	-	-	-	-	+	-
Felaniella usta (Gould, 1861)	-	-	-	+	-	-
Fulvia mutica (Reeve, 1844)	+	-	-	-	-	-
Mactra chinensis Philippi, 1847	+	+	-	+	+	-
Spisula sachalinensis (Schrenck, 1862)	+	-	-	-	+	-
Solen krusensterni Schrenck, 1867	+	-	-	-	-	-
Megangulus venulosus (Schrenck, 1862)	+	+	-	+	+	-
Macoma incongrua (Martens, 1865)	-	-	-	-	+	-
Macoma irus (Hanley, 1845)	-	+	+	-	-	-
Gari californica (Conrad, 1849)	-	-	-	-	+	-
Soletellina atrata Deshayes in Reeve, 1857	-	-	-	-	+	-
Corbicula japonica Prime, 1864	-	-	-	-	+	-
Mercenaria stimpsoni (Gould, 1861)	+	+	-	-	+	-
Protothaca jedoensis (Lischke, 1874)	+	-	+	-	-	-
Protothaca euglypta (Sowerby III, 1914)	+	-	+	+	-	-
Ruditapes philippinarum (Adams et Reeve, 1850)	-	-	-	+	-	-
Gomphina melanaegis Römer, 1861	+	+	+	+	+	+
Irus mitis (Deshayes, 1853)	-	-	-	+	-	-
Irus ishibashianus Kira, 1959	-	-	-	+	-	-
Penitella kamakurensis (Yokoyama, 1922)	-	-	-	+	-	-
Panope abrupta (Conrad, 1849)	+	-	-	-	-	-
Agriodesma navicula (Adams et Reeve, 1850)	-	-	-	+	-	-

the studied areas are open, exposed shores with the exception of beaches which are rather protected by

Table 3. Number of species of bivalves found in different localities of the Korean coast of East Sea.

Locality	No. of species	Reference
Geojedo Island	45	Rho *et al.*, 1998
Ullungdo Island	63	Choe and Lee, 1993
Onsan Bay	25	Rho *et al.*, 1997
Kangung	31	Choi *et al.*, 2000a
Aninjin	15	Kim *et al.*, 1983
Dokto Islands	11	Je *et al.*, 1997
Ulsan Bay	29	Yi *et al.*, 1982

small rocky islets stretching along the coast. The coastline is more or less anthropogenically modified due to the construction of roads, sea-walls and harbours. Some beaches are public.

Studied specimens are stored in the Zoological Museum, Far East State University (ZMFU), Vladivostok. Some of them were shared at Korea Ocean Research and Development Institute (KORDI)

RESULTS AND DISCUSSION

In all, at six sampling sites we found 39 species of bivalve mollusks belonging to 30 genera and 19 families (Mytilidae, Arcidae, Parallelodontidae, Glycymerididae, Ostreidae, Pectinidae, Anomiidae, Plicatulidae, Ungulinidae, Cardiidae, Mactridae, Solenidae, Tellinidae, Psammobiidae, Corbiculidae, Veneridae, Pholadidae, Hiatellidae and Lyonsiidae) (Table 2). This species number is rather high for beach molluscan thanatocoenoses formed under active hydrodynamic regime of coastal waters and found in coarse-grained beach sediments which are unfavourable for shell survival and preservation. According to literature data, the species richness of intertidal and subtidal bivalve taxocoenoses in different localities of the Korean coast of the East Sea varies from 11 to 63 species (Table 3). In East Korean Bay (Tongjoson-man), Evseev (1996) collected only 31 species of Bivalvia. For comparison, the total number of marine bivalves known at present from Korea is

Fig. 3. *Anomia chinensis* Philippi, 1849. Region 1, outer view, height 40.5 mm.

from 282 (Korean Society of Systematic Zoology, 1997) to 349 (Kwon *et al.*, 2001) (in both sources without Corbiculidae).

Species number shows variation among regions: minimum species richness was recorded in Chooksan (5), and maximum was found for the area between Sachondan and the Yongok Stream mouth (21); in other localities, 7, 11, 18 and 18 species were found (regions 2, 3, 4 and 5, respectively). The relatively low numbers reflect not only the taphonomic conditions of formation of beach thanatocoenoses, but also environmental monotony of the coastal zone. In large ria-type bays of the north-western East Sea, we found about 70 species of bivalves on beaches (Lutaenko, 1994a, b), and the number of species from different localities varied between 5 and 43; low diversity was related to the influence of river discharge on the shallow inner parts of bays, where few euryhaline and brackish-water species can exist. Salinity does not control species distribution in the investigated areas of Korea because river run-off is insignificant; annual mean salinity at the surface in the East Sea of Korea is 33.7-33.8‰, and its amplitudes are between 0.8-1.

4‰ (Kang and Jin, 1984b). Another factor strongly influencing the local species composition of mollusks in shallow bays of the Russian coast of the East Sea is temperature. Thermal regime becomes very heterogeneous in summer between inner and outer parts of bays, or semi-enclosed and open areas which leads to differences in the biogeographical composition of molluscan death assemblages. Thus, in Possjet Bay, warm-water species predominated in semi-enclosed bays (61 %), while in open areas their role decreased to 47 % (Lutaenko, 1994b). However, the lack of protected and warmed-up bays along the investigated Korean coast makes it possible to neglect local or latitudinal thermal regime variations when considering species composition patterns of the upper subtidal settlements. Therefore, the profound factor determining local faunal discrepancies should be the type of bottom deposits. For instance, species number generally increases on sandy shores (regions 1, 4, 5), indicating presence of a variety of substrates, i.e., sandy, rocky and mixed coarse-grained sediments.

As we did not have enough material to estimate the differences in species composition of molluscan assemblages from the six areas surveyed, it is desirable to discuss the faunal/biogeographical peculiarities of the entire coast, especially taking into account its short extension (37°50'-36°20'N). For biogeographical analysis, we used the zonal-geographical approach widely accepted in Russian literature (for details, see Scarlato, 1981). All the species collected were assigned to five groups, namely, tropical-subtropical (distributed southward to the Philippines, Vietnam and Indonesia), subtropical (distributed southward to Taiwan and northern part of South China Sea), subtropical-lowboreal (limited both to subtropical seas and the East Sea, southeastern Sakhalin and southern Kurile Islands), lowboreal (limited to the East Sea from Peter the Great Bay, northern Korea and northern Honshu to southwestern Sakhalin, Aniva and Terpenya Bays and the southern Kurile Islands) and circumboreal species (limited mainly to temperate latitudes, both of Atlantic and Pacific Oceans, but partly to the subtropical and arctic zones). Two mollusks, *Modiolus kurilensis* and *Panope abrupta*, are subtropical-boreal species generally limited within the southern Japan and Yellow Sea to the Sea of Okhotsk and eastern Kamchatka, but they were placed in the subtropical-lowboreal group for convenience of consideration. Of the above groups, species with subtropical distribution dominate in the beach thanatocoenoses (14 species, or 38%) (*Mytilus coruscus, Septifer keenae, Arca boucardi, Anadara kagoshimensis, Porterius dalli, Glycymeris cf.rotunda, Crassostrea nipponica, Chlamys farreri, Fulvia mutica, Macoma irus, Protothaca jedoensis, Gomphina melanaegis, Irus ishibashianus* and *Penitella kamakurensis*). Other warm-water mollusks tropical-subtropical (7 species, or 18%) (*Septifer virgatus, Modiolus agripetus, Glycymeris aspersa, Anomia chinensis, Plicatula* sp., *Soletellina atrata* and *Irus mitis*) and subtropical-lowboreal (8 species, or 21%) (*M. kurilensis, Crassostrea gigas, Felaniella usta, Mactra chinensis, Solen krusensterni, Macoma incongrua, Ruditapes philippinarum* and *P. abrupta*) - also play a significant role in the assemblages (Fig. 4). The share of temperate species is lower: seven species (18%) belong to the lowboreal group (*Chlamys swiftii, Mizuhopecten yessoensis, Spisula sachalinensis, Megangulus venulosus, Mercenaria stimpsoni, Protothaca euglypta* and *Agriodesma navicula*) and only two species (5%) are assigned to the circumboreal group (*Mytilus galloprovincialis* and *Gari californica*). It should be noted that the latter two species, being circumboreal, in fact, do not penetrate to the arctic zones and can be considered as rather warm-temperate mollusks. Thus, *M. galloprovincialisis* spread as far north as southern Sakhalin (Moneron Island) and Kunashir Island (southern Kurile Islands) (Ivanova and Lutaenko, 1998). The status of *G. californica* is not clear: Coan (2000) synonymized western Pacific *Gari* (*Gobraeus*) *kazusensis* (Yokoyama, 1922) with the former species, which was originally described from the Pacific coast of North America (south to California, 24.6°N). Higo *et al.* (1999) mentioned *G. kazusensis* as inhabiting coasts of the Kurile Islands, the Sea of Okhotsk and Kamchatka, but this was not confirmed by Russian authors; according to Scarlato (1981), this species is distributed as far north as northern Hokkaido and Peter the Great Bay on the continental coast of the East Sea.

Biogeographically, the studied fauna from beach assemblages is warm-water, subtropical in character: 77% of species are subtropical in origin (i.e., subtropical proper and subtropical-lowboreal) and tropical-subtropical, and only one-fifth (23%) represents cold-water and temperate species. Of course, thorough collecting in the upper subtidal zone (down to 20-30 m) would allow to add with more cold-water species.

The eastern coast of Korea could be divided into two regions with respect to ophiuran biogeography (Shin and Koh, 1993), and a clear-cut boundary lies in the middle of the broad band proposed in a classic work by Nishimura (1965), i.e., roughly around Yeongil Bay. The northern area is characterized by influence of the North Korean Cold Current. In light of such relatively cold conditions (with mean SSTs between 16 and 15℃) characterizing the study area as temperate (mild-temperate according to the scheme of bioclimatic zonation of the East Sea of Kafanov *et al.*, 2000), it is surprising that we found representatives of many tropical and subtropical genera which are lacking in the north-western part of the sea (Scarlato, 1981), namely, *Porterius, Spondylus, Anomia, Fulvia, Soletellina* and *Irus* (Plate 1); another genus not known from the latter area, Penitella, is distributed in the boreal Pacific with several species (Kennedy, 1989). Two families, Plicatulidae and Parallelodontidae, are not found to the north of the North Korean-Russian border along the continental coast of the East Sea and, therefore, in total six genera and two families are not represented in Russian waters of the sea. At the same time, some thermophilous, tropical-subtropical and subtropical species living in shallow waters of Peter the Great Bay (42°N) (e.g., *Anadara broughtonii, Musculista senhousia, Dosinia japonica, Dosinia penicillata, Trapezium liratum, Solen strictus, Macoma tokyoensis and Mactra veneriformis*) have not been collected in the study area. They are typical representatives of embaymental fauna inhabiting protected bays but a majority of them were not recorded even in Yeongil Bay located further south of the studied coast of Gangwon and Gyeongsangbuk Provinces (Lutaenko and Je, unpublished data).

All above-mentioned thermophilous genera are distributed to the north along the island coast of the East Sea, in Honshu and Hokkaido, which is explained by influence of the warm Tsushima Current, a branch of the Kuroshio, flowing into the Soya Strait between Sakhalin and Hokkaido. The bivalve fauna of the Japanese coast of the sea in the same latitudes is markedly different from the Korean one by the presence of a significant number of tropical-subtropical and subtropical species and by a higher species richness (Habe, 1956; 1973; Kuroda, 1957; Ito, 1990; Ito *et al.*, 1986; Fujii, 1987; Miyamoto and Nunomura, 1999). For example, among genera and species not found in the north-western East Sea, *Plicatula* sp. is distributed as far north as Oga Peninsula (about 40°N), *Anomia chinensis* southern Hokkaido, *Fulvia mutica* Oga Peninsula and Mutsu Bay in northern Honshu (Yamamoto and Habe, 1959), *Irus mitis* Tsugaru Peninsula; *S. atrata* is known in Kyushu and southern Honshu (Higo *et al.*, 1999). *I. ishibashianus* and *Porterius dalli* even penetrate to southern Sakhalin, inhabiting coastal waters of small Moneron Island (Kafanov, 1991b; Kafanov and Lutaenko, 1994). Generally, the most sharp northern boundary of distribution of thermophilous families along Japanese coast is observed around the Tsugaru Strait (41-42°N) (Kafanov, 1991a). Scarce data on the

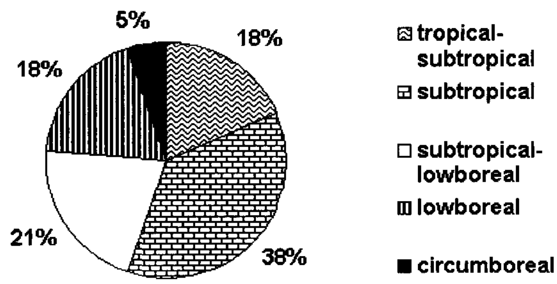

Fig. 4. Biogeographical (zonal-geographical) composition of bivalve mollusk assemblages in the study area.

molluscan distribution in the eastern coast of North Korea demonstrate that the fauna of East Korean Bay is very impoverished and consists mainly of boreal elements: all subtidal mollusks found in the former bay occur now in Peter the Great Bay, and the share of warm-water species in East Korean Bay reaches only 10-15% (Evseev, 1996). However, in this bay material was collected from a limited number of stations at depths less than 11 m, while a majority of warm-water species concentrates in the upper (0 to 5-10 m) horizons of subtidal zone. For instance, representatives of the thermophilous genus *Gomphina* were not recorded in Evseev's (1996) study though they are known from the North Korean coast (Lutaenko, 2001b). It seems inadequate sampling technique leaded to such a small number (31 species), which is too low for this latitude.

Along with qualitative collecting, we have made some observations on the abundance of shell material washed ashore. In region 1, the most abundant species was a venerid *Gomphina melanaegis* with a high proportion of young specimens; other common species on the beach were *Setifer virgatus, Mytilus galloprovincialis, Glycymeris* cf. *rotunda, Mactra chinensis* and *Spisula. sachalinensis* (Plates 1-2). The same venerid, *Gomphina melanaegis,* was the predominant species near Jumunjin. In the area between Sachondan and Yongok, a rocky shore intertidal zone was dominated by dense aggregations of *S. virgatus* and *M. galloprovincialis*. The latter species with some conchological features intermediate between *M. galloprovincialis* and *Mytilus trossulus* Gould, 1850 was recorded intertidally on a pier near Jumunjin. In the area of Hanjindan Cape, a small quantity of *M. chinensis* and *Megangulus venulosus* was found on a gravel beach, but the presence of these sand-dwelling species is explained by shellfishing activity of the local population. Around Hupo Bay, *M. galloprovincialis* and *S. virgatus* were remarkably abundant, and *G. melanaegis* and *Mytilus coruscus* were common. *G. melanaegis* and *Ruditapes philippinarum* were found in large quantities on a short sandy beach near Chooksan. Most of other species were collected rarely or occasionally, sometimes

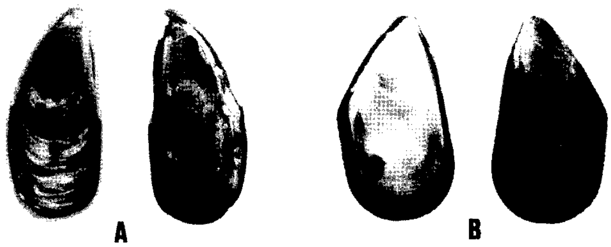

Fig. 5. *Septifer virgatus* (Wiegmann, 1837) (A Jukpyon, reg. 4, shell length 44.8 mm) and *Mytilus galloprovincialis* Lamarck, 1819 (B; Chooksan, reg. 6, shell length 61.1 mm).

only as shell fragments. This should be explained by complicated geomorphology, pebble beach and relative exposure of the beaches to wave action, at least during storms.

In many beaches, *Mytilus galloprovincialis* and *Setifer virgatus* (Fig. 5) were very characteristic species; their shells originated from the intertidal rocky areas located in the immediate neighborhood of the surveyed beaches. *S. virgatus* is an abundant species in many coastal areas of eastern Korea: in Ullung Island, it forms a gregarious mass on rocks; in Aninjin, it occurs abundantly among rocks exposed to strong wave action (Kim *et al.*, 1983); in the area of Geomundo Island (southern coast of Korea), this species participates in the intertidal community *Pollicipes mitella - Tetraclita squamosa japonica - Septifer virgatus* (Kim and Kim, 1985). Further south, in the intertidal zone of Jeju Island (South Sea of Korea), *S. virgatus* was recorded intertidally too (Lee and Jwa, 1988; Lee *et al.*, 1990), but ecologically it seems to be replaced by another mytilid, *Septifer keenae*, which was found to be the first dominant species in the middle and lower intertidal zone (Lee and Hyun, 1991). In our samples, the latter species was very rare. However, *S. virgatus* does not occur in Dokto Islands (Hong, 1981; Je *et al.*, 1997) located far away from the continental Korean coast (37°14'18"N, 131°52'33"E), which might be related to a limited larval exchange between distant populations. Another common mussel species on the shores of the studied area, *M. galloprovincialis*, is also recorded along the entire eastern coast of Korea, being abundant on natural rocks, concrete piling, jetty rocks, hanging strings for mussel culture and natural pebbles and boulders (Je *et al.*, 1990). The presence of morphologically variable shells in our samples may be related to hybridization with *Mytilus trossulus*, as it was suggested for Peter the Great Bay in the northeastern East Sea (Ivanova and Lutaenko, 1998). Je *et al.* (1990) found *Mytilus* sp. in Ohori and Hajodae on the eastern coast of Korea, which differs from typical *Mytilus galloprovincialis* by the shell profile and degree of convexity. Yoo (1992; as *Mytilus edulis galloprovincialis*) studied this species from Jukbyon, Yongdok, Ilkwang and more southerly localities and found that Korean mussel is identical to the Mediterranean representatives based on the mean ratio of anterior adductor muscle scars and hinge plate length to shell height. Many intact, well-preserved (with joined valves) shells of *M. galloprovincialis* and *S. virgatus* in our samples may suggest mass mortalities in local populations due to high summer temperatures. This phenomenon frequently occurs in some bays of the northern Honshu (Tsuchiya, 1983).

Among infaunal bivalves, *Gomphina melanaegis, Mactra chinensis, Spisula sachalinensis* and *Ruditapes philippinarum*, occurred most often on the studied beaches. These commercially important mollusks are common in the subtidal zone on sandy bottom on the eastern coast of Korea (Kwon and Lee, 1999). Shells of *G. melanaegis* collected during this study (Fig. 6) bear some morphologically intermediate features between typical *G. melanaegis* and *Gomphina aequilatera auctt.* (= *Gomphina veneriformis auctt.* non *Donax veneriformis* Lamarck, 1818) (see for details of taxonomy and nomenclature: Lutaenko, 2001b). We may regard this case as hybridization: the presence of intermediate hybridized forms between above-mentioned species is common on the coast of Shimane Prefecture (East Sea side of Honshu) (Tanaka, 1979). It is interesting to note that on the Russian coast of the East Sea (Peter the Great Bay), only typical *G. aequilatera* was recently found; but both these closely related species were recognized on the North Korean coast of the sea (Lutaenko and Yakovlev, 1999). Southwardly, the composition of abundant and exploitable bivalve species changes, e.g., in Deukryang Bay, the commonest infaunal mollusks are *Fulvia mutica, Paphia undulata, S. purpurata, A. broughtonii, Anadara subcrenata, Anadara granosa,* and *Sinonovacula constricta* (Kim and Hur, 1998). In Jeju Island, most abundant infaunal venerids and mactrids are *M. chinensis, D. japonica, Dosinia troscheli, G. aequilatera, R. philippinarum, Paphia euglypta, Paphia schnelliana, S. purpurata,* and *Cyclina sinensis* (Choi *et al.*, 2000b), i.e., more warm-water species, subtropical and tropical-subtropical in zonal-geographical terminology.

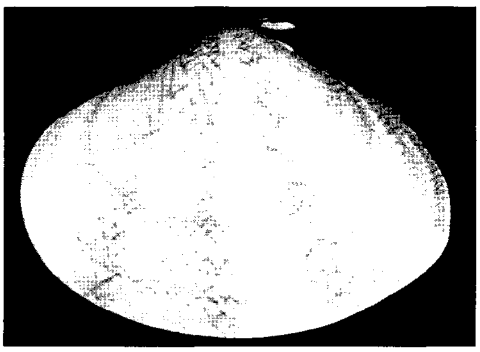

Fig. 6. *Gomphina melanaegis* Römer, 1861 (Gallam, region 3, shell length 48 mm).

At depths exceeding 40-50 m, along eastern Korea, dominant bivalve species are entirely different in their composition from those of the upper subtidal sandy zone: *Acila divaricata, Nucula tenuis, Yoldia notabilis* and *Portlandia toyamaensis* (Je, 1993). These are deposit feeders, occurring under stable physical environments in muddy bottom. On shallow subtidal sandy bottom around Gangneung, a small bivalve *Alvenius ojianus* was found to be the dominant species (Choi *et al.*, 2000a).

In summary, it should be stressed that the studied "beach" fauna in Gangwon and Gyeongsangbuk is, to a large degree, subtropical in character and may be regarded as intermediate between temperate (boreal) fauna of the northern East Sea and subtropical proper fauna of South Sea of Korea. This, most likely, reflects the warm-water character of upper subtidal molluscan assemblages along the studied coast and is related to a weak influence of NKCC on the thermal regime of the upper horizons of the shelf. However, lack of embaymental conditions and relatively low summer temperatures for successful reproduction of a number of thermophilous species found further north along the continental coast of the East Sea, in Peter the Great Bay, impoverish the species composition of the subtidal and beach faunal assemblages. In this respect, we may not agree with the opinion about boreal or temperate nature of the molluscan fauna of the southern Korean coast of East Sea (Tchang *et al.*, 1963; Evseev, 1996). Our data show the tendency that the boundary between subtropical and temperate regions may lie in a broad belt between East Korean Bay and Gangwon-do, or between "Schmidt Utinomi lines" (Nishimura, 1965, fig. 1). The precise position of the boundary would be verified after further collections are taken.

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Plate 1 (for explanation of localities see Table 1)

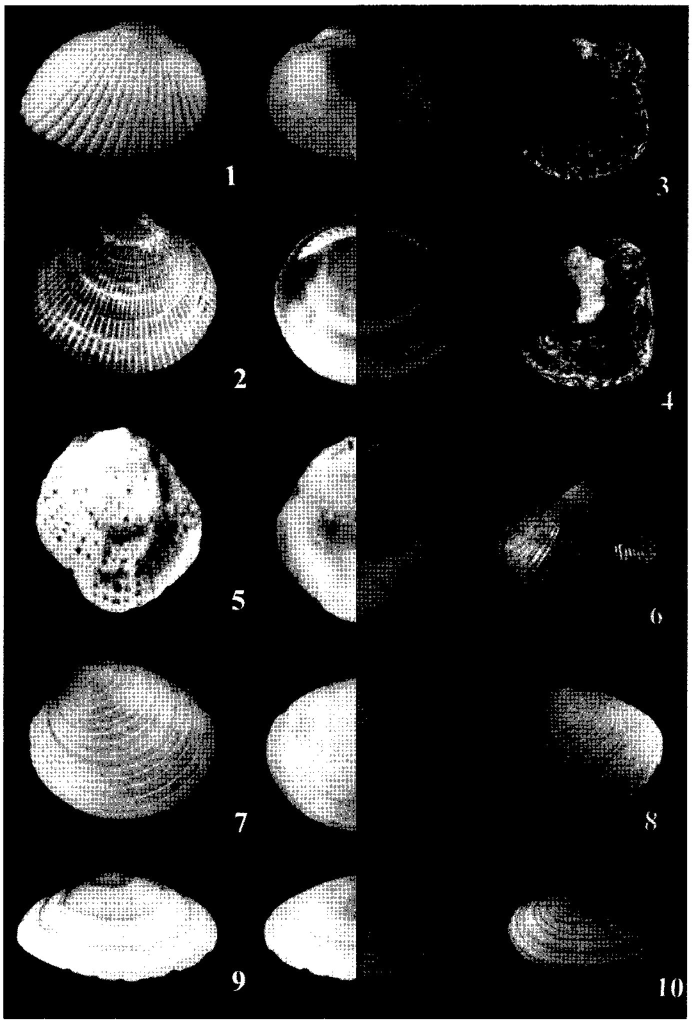

Fig. 1. *Anadara kagoshimensis* (Tokunaga, 1906). Region 4, outer and inner views of the same valve, length 32.6 mm.
Fig. 2. *Glycymeris aspersa* (Adams et Reeve, 1850). Region 5, outer and inner view of the same valve, length 27.2 mm.
Fig. 3. *Anomia chinensis* Philippi, 1849. Region 1, outer view, height 39.9 mm.
Fig. 4. *Anomia chinensis* Philippi, 1849. Region 1, outer view, height 40.5 mm.
Fig. 5. *Plicatula* sp. Reeve, 1856. Region 5, outer and inner views of the same valve, height 24.5 mm.
Fig. 6. *Fulvia mutica* (Reeve, 1844). Region 1, outer view.
Fig. 7. *Mercenaria stimpsoni* (Gould, 1861). Region 4, outer and inner views of the same valve, length 23.8 mm.
Fig. 8. *Mercenaria stimpsoni* (Gould, 1861). Region 1, outer view, length 43.7 mm.
Fig. 9. *Megangulus venulosus* (Schrenck, 1862). Region 4, outer and inner views of the same valve, length 44.8 mm.
Fig. 10. *Megangulus venulosus* (Schrenck, 1862). Region 1, outer view, length 57.5 mm.

Plate 2 (for explanation of localities see Table 1)

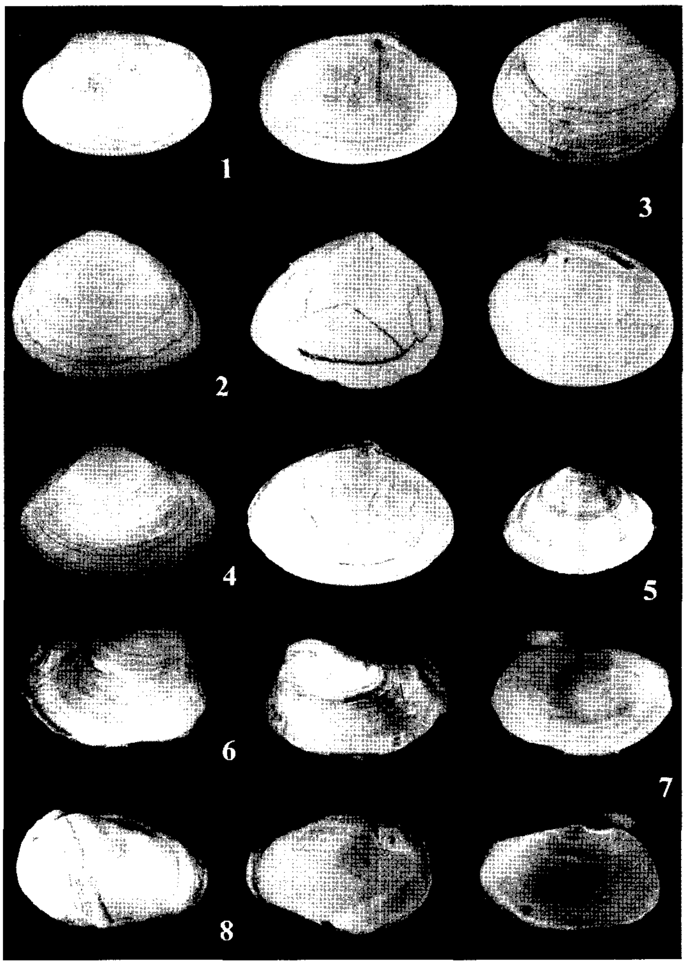

Fig. 1. *Ruditapes philippinarum* (Adams et Reeve, 1850). Region 6, outer and inner views of the same valve, length 33.8 mm.
Fig. 2. *Macoma irus* (Hanley, 1845). Region 4,outer and inner views of the same valve, length 30.5 mm.
Fig. 3. *Protothaca euglypta* (Sowerby III, 1914). Region 4, outer and inner views of the same valve, length 26.8 mm.
Fig. 4. *Mactra chinensis* Philippi, 1847. Region 5, outer and inner views of the same valve, length 62.4 mm.
Fig. 5. *Gomphina melanaegis* Römer, 1861. Region 1, outer view, length 45 mm.
Fig. 6. *Agriodesma navicula* (Adams et Reeve, 1850). Region 4, outer views of valves of the same shell, length 21.7 mm.
Fig. 7. *Agriodesma navicula* (Adams et Reeve, 1850). Inner views of the shell shown in pl. 2, fig. 6.
Fig. 8. *Penitella kamakurensis* (Yokoyama, 1922). Region 4, outer and inner views of the same valve, length 33.6 mm.