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Bivalve mollusks in Ulsan Bay (Korea)

Konstantin A. Lutaenko

A.V. Zhirmunsky Institute of Marine Biology, Far East Branch of the Russian Academy of Sciences, Vladivostok 690041, Russia

ABSTRACT

The bivalve molluscan fauna of Ulsan Bay, East Sea coast of Korea, is summarized, based on original and literature data. The fauna consists of 61 species belonging to 20 families. Seven species are identified only to genus level. Two species (*Carditellopsis toneana* (Yokoyama, 1922), Carditidae and *Fulvia hungerfordi* (G.B. Sowerby III, 1901), Cardiidae) are new records for the East Sea coast of Korea, and one species (*Crenella decussata* (Montagu, 1808), Mytilidae) is a new record for Korea. Biogeographically, Ulsan Bay's bivalve fauna is subtropical with a predominance of tropical-subtropical species, 21 species, or 39% of the total species number, subtropical, 14 species, or 26%, and subtropical-boreal (mostly subtropical-lowboreal), 11 species, 21%, totalling 86%. A remarkable feature of the Ulsan Bay fauna is the presence of tropical-subtropical species not found in Yeongil Bay but common in tidal flats and shallow waters of the Yellow Sea and the southern part of Korea. A cold water mass appearing off the southeast coast of Korea near Ulsan in summer seems responsible for the presence of boreal-arctic species in this area.

Key words: bivalve mollusks, Korea, Ulsan Bay, fauna, biogeography.

INTRODUCTION

Ulsan Bay (Ulsan-man) is one of the bays on the continental coast of the East Sea (Sea of Japan) located in southeastern South Korea (Gyeongsangnam-do, South Gyeongsang Province), about 72 km north-northeast of Busan, the second largest city in Korea. There are no papers dealing specifically with the molluscan fauna of this bay.

The Korean marine molluscan fauna has received much attention in the last twenty years with the publication of color atlases (Kwon O.-K. *et al.*, 1993; 2001; Min D.-K. *et al.*, 2004), general lists (Je, 1989; Lee J.-S. and Min D.-K., 2002), regional lists (Noseworthy *et al.*, 2007), and an annotated and illustrated catalogue of bivalves of the continental coast of the East Sea (Lutaenko and Noseworthy, 2012). However, the fauna is still poorly known at regional and local levels, and the geographical distribution of many species is not clearly understood. We have undertaken a regional survey of bivalves in Ulsan Bay, located in an intermediate biogeographical area between the boreal (temperate) and subtropical (warm-temperate) zones of the East Sea.

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Corresponding author : Konstantin A. Lutaenko
e-mail: lutaenko@mail.ru
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MATERIAL AND METHODS

Material for this study was collected in August 1997 (Fig. 1; Table 1) during a benthic survey conducted by Dr. Lee Eui-Hyeong, formerly of Korea University, and Dr. E.I. Shornikov and Dr. K.A. Lutaenko of the A.V. Zhirmunsky Institute of Marine Biology, Far East Branch of the Russian Academy of Sciences.

The material collected consists of living and dead mollusks (empty shells) collected by dredging at a depth range of 12-56 m on soft substrata in Ulsan Bay at ten stations. The dredge was a small, simple apparatus, 36 cm-wide, designed by Dr. E.I. Schornikov, with a nylon sack with meshes of 0.15 mm x 0.15 mm and an inserted sieve with meshes of 1.5 mm x 1.5 mm (see for details Lee *et al.*, 2000). One

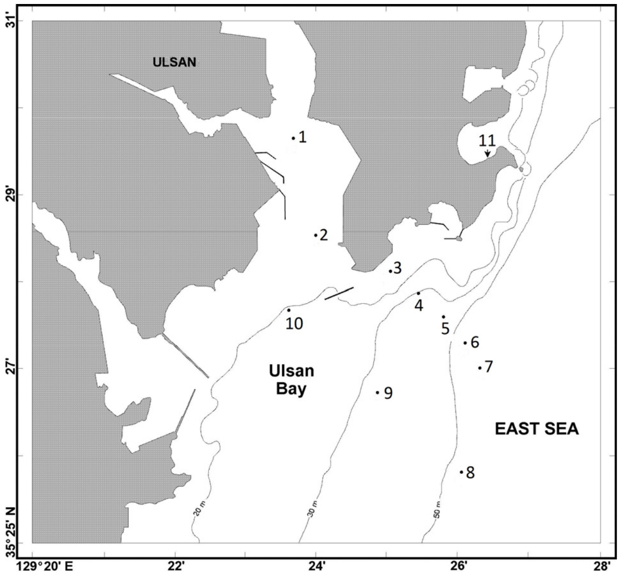

Fig. 1. A map of Ulsan Bay showing sampling stations.

sample was additionally taken at Ilsan Beach on hard substrate with sea grass and algae by snorkelling in a depth of 1-3 m. All dredge samples were sieved to exctract meobenthic organisms; the macrobenthic fraction was fixed in 50-70% alcohol. Macrobenthos was sorted into empty shells and animals collected alive; fixed mollusks were dried after a fixation period of 1-2 years. Mollusks were collected at 11 sampling stations (Fig. 1;Table 1). In total, 1087 specimens of bivalves were examined. The collection studied is deposited in the Zoological Museum, Far Eastern Federal University, Vladivostok (hereafter ZMFU). A list of the ostracod fauna from the same samples was published by Lee *et al.* (2000).

We have also used literature data on bivalve species records taken from ecological/environmental studies by Yi *et al.* (1982), Rho *et al.* (1997), Shin H.C. *et al.* (2001) and Yoon S.-P. *et al.* (2009). Zonal-biogeographical characteristics of molluscan species were taken from the catalogue of the bivalves of the continental coast of East Sea by Lutaenko and Noseworthy (2012); biogeographical analysis and terms based on zonal-geographical approach are described and discussed in detail in a number of works (Scarlato, 1981; Kussakin, 1990; Lutaenko, 1993).

REGIONAL SETTING

Ulsan Bay is a small bay located on the southeastern coast of the Korean Peninsula. The 47 km long Taehwa River passes through downtown Ulsan and flows into Ulsan Bay. The river, which cuts across Ulsan City from east to west, originates in the valley of Giji Mountain and Baekun Mountain. Two other rivers flow into the southern area of the bay, Gosa Stream, between Ulsan and Jangsaeng harbors, and Woihang River, flowing into Onsan Bay, part of Ulsan Bay.

Climatically, one of the most distinct features of the Korean Peninsula is the Asian monsoon system; in

Table 1. List of sampling stations in Ulsan Bay

Station No.	Geographical position	Depth, m	Bottom
1	35º 29' 39" N, 129º 23' 41" E	12	Grey mud
2	35º 28' 33" N, 129º 24' 00" E	15	Grey mud
3	35º 28' 08" N, 129º 25' 03" E	15	Coarse sand
4	35º 27' 53" N, 129º 25' 27" E	31	Grey mud
5	35º 27' 37" N, 129º 25' 48" E	43	Grey mud
6	35º 27' 19" N, 129º 26' 06" E	55	Grey mud
7	35º 27' 01" N, 129º 26' 18" E	56	Grey mud
8	35º 25' 49" N, 129º 26' 04" E	53	Grey mud
9	35º 26' 44" N, 129º 24' 53" E	34	Grey sandy mud
10	35º 27' 30" N, 129º 23' 37" E	22	Grey mud
11 (Ilsan Beach)	35º 29' 27" N, 129º 26' 25" E	1–3	Rocky bottom

winter cold, dry conditions prevail; in summer, a warm, moist climate exists owing to the influence of a local southeasterly flow spiraling from the quasi-stationary, semi-permanent North Pacific high pressure system to the southeast. Therefore, most of Korea experiences cold, dry winters, but hot and humid summers (Kwon and Lee, 2010). Annual mean air temperatures around Ulsan are between 13º C and 14º C; in January around 1-2º C, and in August 24º C (Kwon and Lee, 2010). Mean sea surface temperatures (SSTs) around Ulsan Bay are between 17° and 18° C (http://www.worldclimateguide.co.uk). However, the mean SSTs in the vicinity of the coast are generally lower than those in off-shore regions (Kang and Jin, 1984b). Maximum sea temperatues in Ulsan can reach as high as 26° C in August, with a minimum of 13° C in February and March (http://www.worldclimateguide.co.uk). The annual mean salinity at the sea surface in the area off Ulsan is between 33.5 and 33.7‰, and 34.05‰ at a depth of 30 m (Kang and Jin, 1984a). The eastern coast of South Korea has small tidal differences, a third of one meter at the most (Kwon and Lee, 2010). It is well known that a cold water mass appears off the southeast coast of Korea near Ulsan in summer (Lee K.-B., 1978; Kim C.H. and Kim K., 1983; Lee J.C. and Na J.Y., 1985). The upwelling cold waters are saltier than the resident surface waters, and an extraordinarily high concentration of dissolved oxygen suggests that the upwelling waters are closely connected to the southward flowing North Korea Cold Current (Lee T. and Kim I.-N., 2003). The lowest surface water temperature appears near the coast, and this phenomenon is the most remarkable characteristic of the coastal cold water in Korea: in August, SSTs can drop to 17-20° C around Ulsan, while they reach 25-26.9° C offshore (Lee K.-B., 1978). At 20 m deep, temperatures can be as low as 13-15° C near the coast between Ulsan and Pohang in August, while they increase to 24-25° C offshore (Lee J.C. *et al*., 2003).

The substrate of the coastal area south of Yeongil Bay is composed of clay or mud (Shin and Koh, 1993). At sampling stations in Ulsan Bay, grey mud predominated, but coarse sand was found at one station (Table 1).

The coastal waters of Ulsan Bay are polluted with heavy metals: the levels of Cd, Pb, Hg, Cu, Zn, Co, and Mn were very high in the tissues of the mussel *Mytilus galloprovincialis* Lamarck, 1819, and comparable with elevated concentrations of these elements in *Mytilus* sp. reported for other geographical areas (Szefer *et al*., 2004). In Ulsan Bay, the concentrations of Cu, Pb and Zn in bottom sediments began to increase during the 1960s, but have remained almost unchanged since 1970 (Lee K.W. *et al*., 1988). Approximately, 280,000 t and 300,000 t of domestic and industrial waste, respectively, is discharged daily into the coastal region from Ulsan City and industrial complexes (Khim *et al*., 2001).

Ulsan City was historically a fishing port and agricultural marketing centre but, since the opening of rail and road communications to Seoul and Busan in 1962, it has developed as an industrial centre. Now, Ulsan is home to the world's largest auto production complex and fifth largest automaker, the biggest South Korean shipyard and shipbuilder, and the globe's second largest petrochemical complex; it is regarded as one of the Great Industrial Cities (Jakobs, 2011). Thus, it is especially important to study the regional biota due the to rapid change of the marine environment in the last decades.

ANNOTATED LIST OF BIVALVE MOLLUSKS COLLECTED IN ULSAN BAY

Family **Nuculidae** Gray, 1824

1. ***Acila*** sp.

Sampling station: 10.
Material examined: 1 specimen.
Occurrence: A valve fragment was collected at a depth of 22 m, in mud.

2. ***Nucula (Leionucula) tenuis*** (Montagu, 1808)
Plate 1, fig. B

Sampling stations: 1, 4-9.
Material examined: 579 specimens.
Occurrence: Live specimens were collected at a depth of 12-56 m, in mud and sandy mud; empty shells at

43-56 m.

Comments: A close species is *Nucula* (*Leionucula*) *ovatotruncata* (Scarlato in Volova et Scarlato, 1980) depicted by Scarlato (1981) and Lutaenko and Noseworthy (2012), although it was synonymized with *N. tenuis* by Coan *et al.* (2000). *N. ovatotruncata* is differentiated from *N. tenuis* by the less dorso-ventrally broadened shell and the relatively shorter resilifer (Scarlato 1981). *N. ovatotruncata* is believed to be distributed in southern Primorye (between Possjet and Kievka Bays) in the northwestern East Sea and in the South Kurile Islands area (between Hokkaido and Kunashir Isls.) but it has never been recorded by Japanese malacologists. Other related species are *Nucula mirifica* Dall, 1907 and Nucula niponica Smith, 1885. Korean specimens from Ulsan and Yeongil bays (Lutaenko *et al.*, 2003) resemble, in shell outline, the Chinese *N. tenuis* figured by Xu (1984, pl. 1, fig. 4) and a specimen designated as "*Nucula paulula* A. Adams" in Ito *et al.* (1986, pl. 34, fig. 8) from off the Noto Peninsula. According to Xu (1999), *N. tenuis* occupies the greater part of the Yellow Sea, and it is found also in the South Sea of Korea (Korea Strait) (Je *et al.*, 1991). Kamenev (2013) recorded this species as deep as 1075 m in the East Sea.

3. ***Nucula* (*Nucula*) *paulula*** A. Adams, 1856
Plate 1, fig. A

Sampling station: 3.
Material examined: 1 specimen.
Occurrence: An empty shell was taken at a depth of 15 m, in coarse sand.

Family **Yoldiidae** Dall, 1908
4. ***Yoldia* (*Cnesterium*) *notabilis*** Yokoyama, 1922
Plate 1, fig. C

Sampling stations: 1, 5-10.
Material examined: 27 specimens.
Occurrence: Live mollusks were collected at a depth of 12-55 m, and empty shells at 34-56 m, in mud and sandy mud.

5. ***Portlandia*** sp.

Sampling station: 10.
Material examined: 2 specimens.
Occurrence: Empty shells were taken at a depth of 22 m, in mud.

Family **Arcidae** Lamarck, 1809
6. ***Arca boucardi*** Jousseaume, 1894
Plate 1, fig. D

Sampling station: 5.
Material examined: 1 specimen.
Occurrence: An empty shell was taken at a depth of 43 m, in mud.

7. ***Striarca symmetrica*** (Reeve, 1844)
Plate 1, fig. F

Sampling station: 10.
Material examined: 2 specimens.
Occurrence: Empty shells were collected at a depth of 22 m, in mud.
Comments: We follow a new system of Carter *et al.* (2011) and assign this species to the tribe Striarcini MacNeil, 1937 in the subfamily Noetiinae R. Stewart, 1930 which was previously regarded as a separate family, Noetiidae.

Family **Mytilidae** Rafinesque, 1815
8. ***Mytilus* (*Mytilus*) *galloprovincialis*** Lamarck, 1819
Plate 1, fig. G

Sampling stations: 1, 11.
Material examined: 4 specimens.
Occurrence: Empty shells were collected at a depth of 1-12 m.

9. ***Musculista senhousia*** (Benson in Kantor, 1842)

Sampling station: 6.
Material examined: 3 specimens.
Occurrence: Empty shells were taken at 55 m, in mud.

10. ***Septifer* (*Mytilisepta*) *virgatus*** (Wiegmann, 1837)
Plate 1, fig. J

Sampling station: 3.
Material examined: 2 specimens.
Occurrence: Empty shells were taken at a depth of 15 m, in coarse sand.
Comments: We have in our possession only subadult specimens of *S. virgatus*. This species is bluish in color and adults have smoothish shells, although juvenile specimens, which have fewer and larger, rounded ribs, may be purplish.

11. ***Modiolus* (*Modiolus*) *kurilensis*** Bernard, 1983
Plate 1, fig. H

Sampling station: 11.
Material examined: 1 specimen.
Occurrence: A live specimen was collected at a depth 1-3 m, among sea grass and algae.

12. ***Crenella decussata*** (Montagu, 1808)
Plate 1, fig. E

Sampling stations: 5, 6.
Material examined: 2 specimens.
Occurrence: Empty shells were collected at a depth of 43-55 m, in mud.
Comments: A new record for Korea. This species was previously known from the northern Pacific including the East Sea (Peter the Great Bay and western Sakhalin), being a widely distributed boreal-arctic species (Scarlato, 1960; 1981; Coan *et al*., 2000). Scarlato (1960) described a southern subspecies, *Crenella decussata laticostata* Scarlato, 1960 characterized by a higher shell with strong widely-spaced radial riblets, and distributed in the East Sea and the southern and northern Kurile Islands. As Huber (2010) mentioned, Adams (1862) described *Crenella casta* A. Adams, 1862, *C. cornea* A. Adams, 1862, *C. crocea* A. Adams, 1862, and *C. sculptilis* A. Adams, 1862 from the East Sea, but their types were never depicted and they could not be located in the Natural History Museum (London). These species were listed as valid in the catalogue of Higo *et al*. (1999) in the genus *Arvella* Bartsch in Scarlato, 1960 but their relationship with other North Pacific *Crenella* Brown, 1827 and *Solamen* Iredale, 1924 are not known. *Arvella* includes two large species, *A. japonica* (Dall, 1897), shell length up to 37 mm, distributed in the northern East Sea, southern Sea of Okhotsk, south Kurile Islands and Hokkaido, and *A. manshurica* Bartsch in Scarlato, 1960, shell length up to 43 mm, an endemic species of the Sea of Okhotsk (eastern Sakhalin, Sakhalinsky Bay, Shantar Islands, western Kamchatka, and Hokkaido) (Scarlato, 1981). Arvella has clear radial ribs and is rather close to *Musculus* Röding, 1798 ("rhomboidal-ovate, solid, rougher radial sculpture and larger than *Crenella*, brownish and varnished periostracum" (Huber, 2010, p. 547)). *A. manshurica* was synonymized with *C. decussata* by Higo *et al*. (1999) which is not substantiated at all. On the other hand, Habe (1977), Kafanov (1991) and Higo *et al*. (1999) kept as distinct *Crenella yokoyamai* Nomura, 1932 (nom. nov. pro *Crenella divaricata* Yokoyama, 1922 non d'Orbigny, 1847) (Yokoyama, 1922; Nomura, 1932) which is regarded as a synonym of *C. decussata*, along with *C. decussata laticostata* (Coan *et al*., 2000; Coan and Valentich-Scott, 2012). Scarlato (1981) did mention the resemblance of *C. decussata laticostata* and *C. yokoyamai*. Illustrations of syntypes of *C. divaricata* (Yokoyama, 1922, pl. 15, figs. 10, 11; Oyama, 1992, pl. 27, figs. 3, 4) show that this species (*C. yokoyamai*) is indeed a synonym of *C. decussata* (3 syntypes in the University Museum, University of Tokyo: http://www.um.u-tokyo.ac.jp/web_museum/database_en.html). It is of interest that Yokoyama (1922) mentioned that *C. decussata* lives in the Korea Strait and he was aware of the species described by Adams (1862).

The Pliocene *Crenella delicatula* Yokoyama, 1926 (holotype in the University Museum, University of Tokyo: http://www.um.u-tokyo.ac.jp/web_museum/database_en.html) and *Crenella parvula* Yokoyama, 1926 (3 syntypes in the University Museum, University of Tokyo: http://www.um.u-tokyo.ac.jp/web_museum/database_en.html) (Yokoyama, 1926, p. 301. pl. 36, figs. 7 and 8, respectively; Sawane Formation, Sado Is.) has nothing in common with Recent *C. decussata*. Higo *et al.* (1999) mentioned *C. delicatula* as a "synonym" of *C. yokoyamai*; WoRMS (http://www.marinespecies.org/aphia.php-p=taxdetails&id=539117) takes the former species as a synonym of *C. decussata*. An illustration of *C. yokoyamai* in Ito *et al.* (1986, pl. 40, fig. 1) from the eastern East Sea is identical with our material from Ulsan Bay. Much work needs to be done to revise this regional complex of Crenellinae.

13. ***Lithophaga*** sp.

Sampling station: 5.
Material examined: 1 specimen.
Occurrence: A valve fragment was collected at a depth of 43 m, in mud.

Family **Ostreidae** Rafinesque, 1815
14. ***Crassostrea gigas*** (Thunberg, 1793)
Plate 1, fig. I

Sampling station: 5.
Material examined: 1 specimen.
Occurrence: An empty shell was taken at a depth of 43 m, in mud.

Family **Pectinidae** Wilkes, 1810
15. **Pectinidae** sp. juv.

Sampling stations: 3, 5, 10.
Material examined: 3 specimens.
Occurrence: Empty shells were taken at a depth of 15-43 m.

Family **Thyasiridae** Dall, 1900
16. ***Axinopsida subquadrata*** (A. Adams, 1862)

Sampling stations: 1, 4-10.
Material examined: 46 specimens.
Occurrence: Live mollusks were collected at a depth of 12-55 m, in mud and sandy mud; empty shells were found down to a depth of 56 m.
Comments: Lutaenko and Noseworthy (2012) and Kamenev (2013) stated that further study of this species and comparison with the widely-distributed north-eastern Pacific *Axinopsida sericata* (Carpenter, 1864) are required. Moreover, a number of lucinid and/or thyasirid species described by A. Adams (1862) from the East Sea as *Myrtea* and *Cryptodon* were nearly forgotten and subsequently cited (as *Myrtea, Thyasira* and *Axinopsida*) only a few times in catalogues of the Japanese fauna (Kuroda and Habe, 1952; Higo *et al.*, 1999). They are much in need of critical revision.

17. ***Thyasira tokunagai*** Kuroda et Habe, 1951
Plate 2, fig. A

Sampling stations: 5, 6, 8-10.
Material examined: 12 specimens.
Occurrence: Live mollusks were collected at a depth of 34-53 m, in mud and sandy mud; empty shells were taken at 22-55 m.

Family **Carditidae** Férussac, 1822
18. ***Carditellopsis toneana*** (Yokoyama, 1922)
Plate 2, fig. D

Sampling station: 3.
Material examined: 4 specimens.
Occurrence: Empty shells were collected at a depth of 15 m, in coarse sand.
Comments: A new record for the East Sea coast of Korea. In Korea, *C. toneana* was previously found in Jeju Island (Min D.-K. *et al.*, 2004; Noseworthy *et al.*, 2007). It is distributed from northwestern Honshu (Iwate Prefecture) and southwards in the East Sea, including Sado Island, to Kyushu, and along the Pacific side of Japan at a depth of 20-150 m, in fine sand (Higo *et al.*, 1999).

Family **Crassatellidae** Férussac, 1822
19. ***Salaputium cf. unicum*** Hayami et Kase, 1993-
Plate 2, fig. C

Sampling station: 5.

Material examined: 1 specimen.
Occurrence: An empty shell was collected at a depth of 43 m, in mud.
Comments: This small-sized crassatellid, rarely exceeding 3 mm in maximum length, was described from subtidal caves of Ie, Shimoji, and Irabu Islets, Ryukyu Islands (Hayami and Kase, 1993), and then Lutaenko *et al*. (2003) recorded this species from Yeongil Bay. However, it was observed that specimens from the latter locality have a slightly concave posterodorsal margin, while specimens from the Ryukyu Islands exhibit a slightly convex posterodorsal margin, and bear more sharp commarginal lamellae on the shell surface. Recently, Huber (2010) stated that another allied species, *Crassatella sublamellata* Kobelt, 1885 was originally described from Japan, and a small series of similar specimens has been available from subtidal caves at Palau; the smallest are, in shape, very close to S. unicum, whereas the largest approaches *C. sublamellata*. Huber (l.c.) believes that there is little doubt that S. unicum is only a juvenile cave form of C. sublamellata, changing shape during its growth and becoming more elongate and subrectangular in adults. The status of the genus *Salaputium* Iredale, 1924 itself is not clear; there are about 13 species mostly from Australia.

Family **Cardiidae** Lamarck, 1809
20. ***Fulvia hungerfordi*** (G.B. Sowerby III, 1901)
Plate 2, fig. F

Sampling station: 10.
Material examined: 3 specimens.
Occurrence: Empty shells were taken at a depth of 22 m, in mud.
Comments: A new record for the East Sea coast of Korea. This species is recorded for Jeju Is. (Noseworthy *et al*., 2007).

Family **Chamidae** Lamarck, 1809
21. **Chama** sp. juv.

Sampling station: 3.
Material examined: 2 specimens.
Occurrence: Empty juvenile shells were taken at a depth of 15 m, in coarse sand.

Family **Lasaeidae** Gray, 1842
22. ***Nipponomysella oblongata*** (Yokoyama, 1922)
Plate 2, fig. B

Sampling station: 10.
Material examined: 1 specimen.
Occurrence: An empty shell was found at a depth of 22 m, in mud.

Family **Kelliellidae** P. Fischer, 1887
23. ***Alveinus ojianus*** (Yokoyama, 1927)
Plate 2, fig. E

Sampling stations: 3, 5, 9, 10.
Material examined: 81 specimens.
Occurrence: Empty shells were taken at a depth of 15-43 m, in mud, sandy mud, and coarse sand.

Family **Mactridae** Lamarck, 1809
24. ***Raeta (Raetellops) pulchella*** (Adams et Reeve, 1850)
Plate 2, fig. H

Sampling stations: 4-6, 9, 10.
Material examined: 34 specimens.
Occurrence: Empty shells were taken at a depth of 22-43 m, and a living mollusk at 55 m, in mud and sandy mud.
Comments: *Neaera tenuis* Hinds, 1844 may be an earlier name for this species (Huber, 2010). According to Higo *et al*. (1999), this species is distributed as far south as the South China Sea and Australia, and is known from the northern East Sea (Dulenina, 2013); this species may represent a complex of species. At least, specimens from Singapore (Wong, 2009, fig. 16a, b) are dissimilar in shell shape to typical East Sea specimens.

Family **Tellinidae** Blainville, 1814
25. ***Macoma (Macoma) incongrua*** (Martens, 1865)
Plate 2, fig. G

Sampling station: 5.
Material examined: 1 specimen.
Occurrence: An empty shell was taken at a depth of 43 m, in mud.

26. ***Macoma* (*Macoma*) *tokyoensis*** Makiyama, 1927
Plate 2, fig. I

Sampling station: 5.
Material examined: 2 specimens.
Occurrence: Empty shells were taken at a depth of 43 m, in mud.

27. ***Angulus vestalioides*** (Yokoyama, 1920)
Plate 2, fig. K

Sampling station: 10.
Material examined: 4 specimens.
Occurrence: Empty shells were taken at 22 m, in mud.

28. ***Moerella iridescens*** (Benson, 1842)
Plate 2, fig. J

Sampling stations: 5, 9, 10.
Material examined: 8 specimens.
Occurrence: Empty shells were taken at a depth of 22-43 m, in mud and sandy mud.
Comments: This species was previously known only from Busan on the East Sea coast of Korea (Lutaenko and Noseworthy, 2012).

Family **Semelidae** Stoliczka, 1870
29. ***Theora* (*Endopleura*) *lubrica*** A.A. Gould, 1861
Plate 3, fig. C

Sampling stations: 1, 2, 4-6, 8, 10, 11.
Material examined: 104 specimens.
Occurrence: Empty shells were taken at a depth of 1-55 m, and live specimens from 22-53 m, in mud.

Family **Solecurtidae** d'Orbigny, 1846
30. ***Azorinus abbreviatus*** (Gould, 1861)
Plate 3, fig. A

Sampling station: 10.
Material examined: 4 specimens.
Occurrence: Empty shells were taken at a depth of 22 m, in mud.

Family **Ungulinidae** Gray, 1854
31. ***Felaniella sowerbyi*** Kuroda et Habe, 1951

Sampling station: 9.
Material examined: 2 specimens.
Occurrence: Empty shells were taken at a depth of 34 m, on sandy mud.

32. ***Cycladicama cumingii*** (Hanley, 1844)
Plate 3, fig. B

Sampling stations: 5, 9, 10.
Material examined: 24 specimens.
Occurrence: Empty shells were taken at a depth of 22-43 m, in mud and sandy mud.

33. ***Cycladicama cf. lunaris*** (Yokoyama, 1927)
Plate 3, fig. D

Sampling stations: 5, 6, 9, 10.
Material examined: 11 specimens.
Occurrence: Empty shells were taken at a depth of 22-55 m, in mud and sandy mud.

Family **Veneridae** Rafinesque, 1815
34. ***Dosinia* (*Dosinella*) *penicillata*** (Reeve, 1850)
Plate 3, fig. F

Sampling stations: 5, 10.
Material examined: 2 specimens.
Occurrence: Empty shells were taken at a depth of 22-43 m, in mud.
Comments: Records of "*Dosinella corrugata* (Reeve, 1850)" from Korea (Min D.-K. *et al.*, 2004) clearly represent true *D. penicillata*. This species was long known in the Russian literature as *Dosinia angulosa* (Philippi, 1847) (Kafanov and Lutaenko, 1997). *Dosinia trailli* A. Adams, 1855 might be a synonym of *D. penicillata* (see possible types: Fischer-Piette and

Delmas, 1967, pl. 13, figs. 4-12).

35. ***Ruditapes philippinarum*** (A. Adams et Reeve, 1850)
Plate 3, fig. E

Sampling stations: 1, 11.
Material examined: 7 specimens.
Occurrence: Live specimens were collected at a depth of 1-12 m, in mud and among sea grass and algae.

36. ***Protothaca* (*Protocallithaca*) *adamsii*** (Reeve, 1863)
Plate 3, fig. G

Sampling stations: 3, 7, 8, 10.
Material examined: 6 specimens.
Occurrence: Live specimens were collected at a depth of 22-56 m, and empty shells at 15-22 m, in mud and coarse sand.
Comments: *P. adamsii* (type species of *Protocallithaca* Nomura, 1937) is very similar to *Protothaca* Dall, 1902 in cardinal teeth characteristics and finely crenulated inner ventral margin, but its external shell sculpture resembles *Callithaca* Dall, 1902, and it is better to be assigned to the subgenus *Protothaca* (*Protocallithaca*) (Matsubara, 2009).

Family **Myochamidae** P.P. Carpenter, 1861
37. ***Myadora japonica*** Habe, 1950
Plate 3, fig. H

Sampling station: 5.
Material examined: 1 specimen.
Occurrence: An empty shell was taken at a depth of 43 m, in mud.

FAUNAL ANALYSIS

A total of 37 species of bivalve mollusks were collected at 11 sampling stations in Ulsan Bay. Taking into account available literature data (Yi *et al.*, 1982; Rho *et al.*, 1997; Shin H.C. *et al.*, 2001; Yoon S.-P. *et al.*, 2009), the combined list of bivalves consists of 61 species, among which 8 taxa are indentified to genus or family level (Table 2). Comparison of species richness of bivalve molluscan faunas in various regions of the eastern and southern coasts of Korea shows that the richest areas are Goseong-gun in Gangwon Province and Yeongil Bay in Gyeongbuk Province, 85 and 98 species, respectively (Table 3). Bivalve faunas of various islands are noticeably poor, from 9 to 33 species, and even Geoje Island, a large island off the southeast coast, has only 45 reported species. In contrast, the Jeju Island bivalve fauna, though more subtropical than that of the continental coast of Korea, is very rich with 225 species recorded (Table 3). Such differences can be explained by insuffient attention given to the study of the regional or local molluscan faunas of Korea, a very shortsighted practice in light of rapid environmental changes, growth of urban areas, and increasing human pressure on coastal zones in the past decades. The entire South Korean coast of the East Sea (south to Busan) is inhabited by 312 species of bivalves (Lutaenko and Noseworthy, 2012).

We believe that bivalve molluscan fauna of Ulsan Bay may include up to 100 species and should not be poorer than that of Yeongil Bay. Additional collecting in Ulsan Bay is needed but, even with our limited material, we can trace some differences with other regions of Korea, and also faunal affinities. At least, 23 species found in Ulsan Bay are not known from Yeongil Bay (*A. divaricata, B. trapezina, S. symmetrica, M. senhousia, C. decussata, G. coralliophaga, S. circumpicta, A. chinensis, C. lemniscata, T. tokunagai, C. toneana, F. hungerfordi, L. undulata, M. venulosus, A. vestalioides, A. abbreviatus, F. sowerbyi, D. penicillata, R. aspera, P. undulata, P. euglypta, P. mirabilis, L. boschasina*). Whereas some of them can be doubtful literature records, others do not appear to inhabit the more northern areas of South Korea (*D. penicillata, B. trapezina, A. abbreviatus, R. aspera, P. undulata*). Distributional ranges of *M. senhousia* and *D. penicillata* in the entire East Sea are discontinuous: they are known from Peter the Great Bay in the north-western East Sea and are absent from mid-Primorye further north (Lutaenko and Noseworthy, 2012) but may be found alive in North Korea. They live only in shallow bays with summer warming sufficient for successful reproduction and

Table 2. A list of species of bivalve mollusks from Ulsan Bay

Species	Yi *et al.*, 1982	Rho *et al.*, 1997	Shin H.C. *et al.*, 2001	Yoon S.-P. *et al.*, 2009	Present paper	Zonal-geographical characteristics
1. *Acila (Acila) divaricata* (Hinds, 1843)	+					s/b
2. *Acila* sp.					+	
3. *Nucula (Leionucula) tenuis* (Montagu, 1808)					+	wdb
4. *Nucula (Nucula) paulula* A. Adams, 1856	+				+	s
5. *Yoldia* sp.	+					
6. *Yoldia (Cnesterium) notabilis* Yokoyama, 1922					+	s/b
7. *Portlandia* sp.					+	
8. *Arca boucardi* Jousseaume, 1894		+			+	s/b
9. *Barbatia (Abarbatia) trapezina* (Lamarck, 1819)	+					t/s
10. *Striarca symmetrica* (Reeve, 1844)	+				+	t/s
11. *Porterius dalli* (E.A. Smith, 1885)		+				s
12. *Mytilus (Mytilus) galloprovincialis* Lamarck, 1819		+			+	s/b
13. *Musculista senhousia* (Benson in Kantor, 1842)	+	+		+	+	s/b
14. *Septifer (Mytilisepta) virgatus* (Wiegmann, 1837)		+			+	t/s
15. *Modiolus (Modiolus) kurilensis* Bernard, 1983		+			+	s/b
16. *Crenella decussata* (Montagu, 1808)					+	b/a
17. *Gregariella coralliophaga* (Gmelin, 1791)		+				t/s
18. *Lithophaga (Leiosolenus) curta* (Lischke, 1874)		+				t/s
19. *Lithophaga* sp.					+	
20. *Crassostrea gigas* (Thunberg, 1793)		+			+	s/b
21. *Striostrea circumpicta* (Pilsbry, 1904)		+				s
22. *Anomia chinensis* Philippi, 1849		+				t/s
23. *Chlamys (Azumapecten) lemniscata* (Reeve, 1853)		+				t/s
24. *Pectinidae* sp. juv.					+	
25. *Axinopsida subquadrata* (A. Adams, 1862)					+	b/a
26. *Thyasira tokunagai* Kuroda et Habe, 1951	+				+	s
27. *Cardita leana* Dunker, 1860		+				t/s
28. *Carditellopsis toneana* (Yokoyama, 1922)					+	s
29. *Salaputium* cf. unicum Hayami et Kase, 1993					+	s
30. *Fulvia hungerfordi* (G.B. Sowerby III, 1901)					+	t/s
31. *Chama* sp. juv.					+	
32. *Lasaea undulata* (Gould, 1861)		+				s
33. *Nipponomysella oblongata* (Yokoyama, 1922)					+	s
34. *Alveinus ojianus* (Yokoyama, 1927)					+	s
35. *Raeta (Raetellops) pulchella* (Adams et Reeve, 1850)	+				+	t/s
36. *Megangulus venulosus* (Schrenck, 1861)		+				lb
37. *Macoma (Macoma) incongrua* (Martens, 1865)					+	s/b
38. *Macoma (Macoma) tokyoensis* Makiyama, 1927	+				+	s
39. *Angulus vestalioides* (Yokoyama, 1920)					+	t/s
40. *Moerella iridescens* (Benson, 1842)						t/s
41. *Theora (Endopleura) lubrica* A.A. Gould, 1861	+		+	+	+	t/s
42. *Azorinus abbreviatus* (Gould, 1861)					+	t/s
43. *Felaniella usta* (Gould, 1861)	+					s/b
44. *Felaniella sowerbyi* Kuroda et Habe, 1951					+	t/s
45. *Cycladicama cumingii* (Hanley, 1844)					+	t/s
46. *Cycladicama* cf. *lunaris* (Yokoyama, 1927)					+	s
47. *Callista (Ezocallista) brevisiphonata* (Carpenter, 1864)		+			+	lb
48. *Dosinia (Dosinella) penicillata* (Reeve, 1850)	+				+	t/s
49. *Ruditapes philippinarum* (A. Adams et Reeve, 1850)		+	+	+	+	s/b
50. *Ruditapes aspera* (Quoy et Gaimard, 1835)		+				t/s
51. *Paphia (Neotapes) undulata* (Born, 1778)	+					t/s
52. *Protothaca (Protothaca) euglypta* (Sowerby III, 1914)		+				s
53. *Protothaca (Protocallithaca) adamsii* (Reeve, 1863)					+	lb
54. *Irus (Irus) irus* (L., 1758)		+				t/s

55. *Irus* sp.		+		
56. *Pseudoirus mirabilis* Deshayes, 1853		+		s
57. *Aspidopholas* sp.		+		
58. *Hiatella orientalis* (Yokoyama, 1920)		+		s/b
59. *Myadora japonica* Habe, 1950			+	s
60. *Entodesma navicula* (A. Adams et Reeve, 1850)		+		wdb
61. *Laternula boschasina* (Reeve, 1860)	+			t/s

Abbreviations: **t/s** – tropical-subtropical species; **s** – subtropical species; **s/b** – subtropical-boreal (mostly subtropical-lowboreal) species; **lb** – lowboreal species; **b/a** – boreal-arctic species (including widely distributed boreal-arctic); **wdb + cb** – widely distributed boreal + circumboreal species.

Notes: *Barbatia* (*Abarbatia*) *trapezina* (Lamarck, 1819) was listed as *Abarbatia lima* (Yi *et al*., 1982), a synonym of the former species; *Striarca symmetrica* (Reeve, 1844) was listed as *Arcopsis symmetrica* (Yi *et al*., 1982); *Mytilus* (*Mytilus*) *galloprovincialis* Lamarck, 1819 was listed as *Mytilus edulis* in Rho *et al*. (1997); *Modiolus* (*Modiolus*) *kurilensis* Bernard, 1983 was listed as *Modiolus modiolus difficilis* in Rho *et al*. (1997), a synonym of the former species; *Striostrea circumpicta* (Pilsbry, 1904) was listed as *Ostrea circumpicta* in Rho *et al*. (1997); *Theora* (*Endopleura*) *lubrica* A.A. Gould, 1861 was listed as *Theora lata* in Yi *et al*. (1982); *Ruditapes aspera* (Quoy et Gaimard, 1835) was listed as *Ruditapes variegatus* in Rho *et al*. (1997), a synonym of the former species; *Irus* (*Irus*) *irus* (L., 1758) was listed as Irus macrophyllus in Rho *et al*. (1997), a possible synomym of the former species; *Entodesma navicula* (A. Adams et Reeve, 1850) was listed as *Agriodesma navicula* in Rho *et al*. (1997); more information on taxonomy can be found in Huber (2010) and Lutaenko and Noseworthy (2012).

Table 3. Species richness of bivalve molluscan faunas in various regions of the eastern and southern coasts of Korea

Region	Number of species	Reference
Goseong-gun (Gangwon Province)	85	Park T.S. *et al.* (2011)
Yeongil Bay	98	Lutaenko *et al.* (2003; 2006)
Ulsan Bay	61	Present paper
Geoje Island	45	Rho *et al.* (1998)
Tokdong (Masan Bay), Charando and Isudo islands (southern coast of Korea)	27	Choe B.L. *et al.* (1995)
Dolsan Islan, South Sea of Korea	9	Kim H.S. and Shin M.K. (1986)
Komundo, Taesambudo, Sangpaekdo islands (South Sea of Korea)	7	Kim H.S. and Kim I.-H. (1985)
Jindo Island (south-western Korea)	33	Kil H.J. *et al.* (2005)
Around Hwawon Peninsula (south-western Korea)	37	Lee Y.G. (1997b); Lee Y.G. and Choi J.M. (2007); including shells from the Holocene deposits
Eastern coast of South Korea (south to Busan)	312	Lutaenko and Noseworthy (2012)
Jeju Island	225	Noseworthy *et al.* (2007)

with muddy bottoms, i.e., typical embayments. In the northern East Sea they are relics of the mid-Holocene climatic optimum (Lutaenko, 1993; Lutaenko and Noseworthy, 2014).

Although the Ulsan Bay bivalve fauna is insufficiently known, we have undertaken an analysis of its biogeographical structure following the zonal-geographical (zonal-biogeographical) approach widely used in the Russian literature (see for extended discussion: Lutaenko and Noseworthy (2014)). We recognize six major zonal-geographical groups: **1**. *tropical-subtropical* (distributed southward to the Philippines, Vietnam, and Indonesia); **2**. *subtropical* (distributed southward to Taiwan and the northern part of the South China Sea); **3**. *subtropical-lowboreal* (limited both to subtropical seas and the East Sea, southeastern Sakhalin, and the southern Kuril Islands); **4**. *lowboreal* (limited to the East Sea from Peter the Great Bay, northern Korea, and northern Honshu to Aniva and Terpenya bays, southwestern Sakhalin, and the southern Kurile Islands); **5**. *widely distributed boreal* (limited to the East Sea and

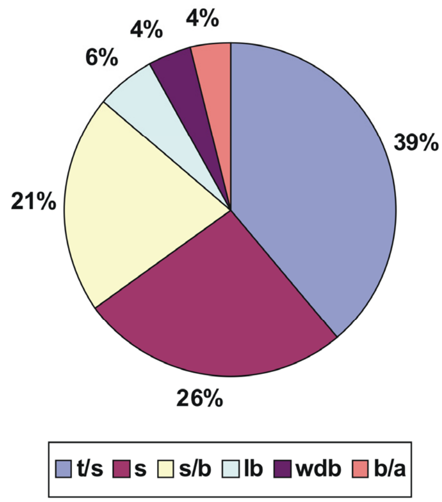

Fig. 2. Zonal-biogeographical composition of the Ulsan Bay bivalve fauna (abbreviations: **t/s** - tropical-subtropical species; **s** - subtropical species; **s/b** - subtropical-boreal (mostly subtropical-lowboreal) species; **lb** - lowboreal species; **b/a** - boreal-arctic species; **wdb** - widely distributed boreal + circumboreal species).

Hokkaido to the Bering Strait, along the Asian coast, and along the northern American coast southward to California), and *circumboreal* (limited mainly to temperate latitudes, both in the Atlantic and Pacific Oceans, but also partly to subtropical and arctic zones); **6**. *boreal-arctic* (limited to both the temperate zone of the Pacific Ocean and the Arctic, and partly to the temperate Atlantic). We checked the geographical distribution of many species using numerous literature sources, and unified zonal-geographical characteristics are given for each species in our catalogue (Lutaenko and Noseworthy, 2012).

The bivalve fauna in Ulsan Bay is dominated by warm-water mollusks: tropical-subtropical (21 species, or 39% of the total species number), subtropical (14 species, or 26%) and subtropical-boreal (mostly subtropical-lowboreal) (11 species, 21%), totalling 86% (Fig. 2). There are also 2 boreal-arctic and several boreal species; therefore, the fauna can be regarded as subtropical with an admixture of boreal and boreal-arctic species (14%). However, the share of wholly subtropical species may increase with more faunal research and a more lengthy list of species. A remarkable feature of the Ulsan Bay fauna is the presence of tropical-subtropical species not found in Yeongil Bay but common in the tidal flats and shallow waters of the Yellow Sea and the southern part of Korea. Thus, even the occurrence of upwelling cold waters in summer around Ulsan does not prevent warm-water mollusks from living in Ulsan Bay. It seems that the area between Yeongil and Ulsan bays is an important intermediate zone where the two faunas meet. We proposed that there is a transition zone marking a decline of cold-water bivalve mollusks and a significant increase of warm-water species between Yeongil Bay and Busan on the continental coast of the East Sea (Lutaenko and Noseworthy, 2014). Similarly, there is a corresponding zone between the Noto Peninsula and Tsugaru Strait in the eastern part of the Sea which is comparable to the earlier "discontinuity belt" of abrupt change in the number of southern elements of Nishimura (1965). This belt marks the boundary between subtropical and boreal zones in the East Sea, or Warm-Temperate and Cold-Temperate zones according to the concept of Briggs (2007).

Y.G. Lee (1997a) studied the Quaternary environments, sea-level changes, and molluscan thanatocoenoses in the continental shelf off Ulsan. At a depth range of 45-158 m (but mostly below 100 m), this author encountered 72 species of Bivalvia and established 17 molluscan assemblages. Among them, the author enumerated species belonging to some genera not found in our shallow-water survey (e.g., *Nuculana*, *Neilonella*, *Limopsis*, *Glycymeris*, *Polynemamussium, Cyclocardia*, *Trapezium, Tridonta* (= *Astarte*), *Cadella*, *Anisocorbula*, etc.). Part of this complex belongs to the last glacial period of low-stand sea level, and it reflects tidal flat embaymental conditions (e.g., *A. boucardi*, *Nipponarca bistrigata* (Dunker, 1866), *Trapezium bicarinatum* (Schumacher, 1817), *Trapezium liratum* (Reeve, 1843), *Moerella jedoensis* (Lischke, 1872), *F. usta*) but these assemblages also include indicator fossils of the Late Pliocene-Pleistocene formations (e.g., *Mizuhopecten tokyoensis hokurikuensis* (Akiyama, 1962)). Thus, this Quaternary complex can be considered to be an initial post-glacial and early-Holocene transgression assemblage of bivalve mollusks having a mixed cold- and warm-water character and formed at the beginning of the development of the Recent East Sea molluscan fauna. Similar shelf deposits around Tsushima contain shells with radiocarbon ages as old as ca. 14000-15000 years BP (Lee Y.G., 2005). This fauna can be compared with those described by G.A. Evseev (1981) for the early stages of the post-glacial transgression in the north-western East Sea; the latter typically includes more cold-water species (*Pododesmus macrochisma* (Deshayes, 1839), *Clinocardium ciliatum* (Fabricius, 1780), *Callista brevisiphonata* (Carpenter, 1864), *Liocyma fluctuosum* (Gould, 1841), *Macoma middendorffi* Dall, 1884, *Macoma lama* Bartsch, 1929, *Mactromeris polynyma* (Stimpson, 1860), etc.). However, the south-western East Sea Late Quaternary molluscan assemblages contain much more warm-water faunal elements. About 15000 ago, Korean shorelines extended seaward by more than 100 km as sea level was lower than the present-day, about 120 m deep (Lee Y.G. *et al*., 2008). Remnants of this post-glacial fauna still exist on the shelf and in embayments in South Korea.

The Ulsan Bay bivalve fauna clearly exhibits wider depth ranges of warm-water bivalves as compared to northern regions of the East Sea (Table 4); this can be explained by the influence of warm currents on the lower subtidal zone of this part of the Sea. Whereas warm-water species in Peter the Great Bay, in the north-western East Sea, prefer the upper subtidal zone, cold-water species concentrate deeper. For instance, in Ussuriysky Bay, an overwhelming majority of subtropical and subtropical-lowboreal mollusks inhabits the 0-30 m depth range but are rare below 31 m; tropical-subtropical species are not recorded deeper than 61 m. In contrast, the number of boreal-arctic species increases with depth. The same trend is observed for the molluscan faunas of Possjet and Amursky bays (Lutaenko and Noseworthy, 2014). In Possjet Bay, open and semi-enclosed areas are clearly differentiated by their biogeographic composition (Golikov and Scarlato, 1967; Scarlato, 1981), and warm-water taxa predominate in semi-enclosed inlets and inner, shallow parts of the bay. The proportion of subtropical and subtropical-lowboreal species in semi-enclosed inlets reaches 46%, while in open areas it is only 12%. This pattern is connected with the heterogeneity of summer temperatures in bays, which allows eurythermal, warm-water, taxa to concentrate in semi-enclosed inlets and inner parts under favourable conditions for spawning.

The same trend of the existence of wider bathymetric ranges of warm-water bivalves is observed along the eastern coast of the East Sea, on the coast of Japan, where the influence of the warm Tsushima Current is very strong (Table 4). *A. boucardi* does not live in the northern part of the sea deeper than 18 m

Table 4. Bathymetric ranges (m) of some warm-water bivalve mollusks found in Ulsan Bay in comparison with other areas of East Sea

Species	Ulsan Bay	Yeongil Bay	Niigata Pref.	Ishikawa Pref.	Wakasa Bay and Hyogo Pref.	Peter the Great Bay and Primorye
Arca boucardi	43	6.5-30	11-210	20-100	41-139	0-18
Musculista senhousia	55					0-6
Alveinus ojianus	15-43	6.5-35.5				0-74
Raeta pulchella	22-55	6.5-30	5-102		39-62	4.5-39
Macoma incongrua	43			40-106		0-30
Macoma tokyoensis	43	12-21				2-12
Theora lubrica	1-55	8.5-28	34-56			3-25
Dosinia penicillata	22-43					2-7
Protothaca adamsii	15-56	6.5-52			87-161	1-45

Notes: Yeongil Bay, Korea (Lutaenko et al., 2003); Niigata Pref. (including Sado Isl.; eastern East Sea) (Ito, 1978, 1985, 1989); Ishikawa Prefecture (Ito et al., 1986); Wakasa Bay and Hyogo Prefecture (eastern East Sea) (Ito, 1967, 1990); Peter the Great Bay and Primorye (north-western East Sea) (Scarlato, 1981; Lutaenko, 1999; 2003; 2006) while it is found on the Japan coast as deep as 210 m, and in Ulsan Bay at a depth of 43 m. *D. penicillata*, a relic of the mid-Holocene warming in Peter the Great Bay, lives there only in semi-enclosed bays and not deeper than 7 m, but it is found at a depth of 22-43 m in Ulsan Bay. In Japan *M. incongrua* has a depth range of 106 m, and in Ulsan Bay to 43 m, while it occurs at a range of 0-30 m in the Russian part of the sea. This important biogeographic phenomenon can be regarded as the displacement of warm-water species into the upper subtidal zone in the high-latitude margin of their range, whereas the occurrence of cold-water species at greater depths in the low-latitude margin of their range, quite common in temperate latitudes, is called “submergence” (Dodd and Stanton, 1981).

The abundance of bottom animals, including bivalve mollusks, and the structure of bottom communities in Ulsan Bay have been studied by a number of researchers (Yi *et al*., 1982; Rho *et al*., 1997; Shin H.C. *et al*., 2001; Yoon S.-P. *et al*., 2009). In the early 1980s, five species were found to be dominant and common in Ulsan Bay: *T. lubrica, M. senhousia, M. tokyoensis, N. paulula, R. pulchella* (Yi *et al*., 1982). Intertidally and partly subtidally, *M. galloprovincialis, C. gigas, S. virgatus, L. undulata and O. circumpicta* were common (Rho *et al*., 1997). Later, *R. philippinarum* with a density of up to 86 ind./m^2 and *T. lubrica* with a density up to 9 ind./m^2 were collected in 1997, both found mostly in the estuary of the Taehwa River. In 2006 three species were dominant: *T. lubrica*, with an average density varying from month to month of 148, 97, 221 and 227 ind./m^2 in February, May, August and November, respectively, *R. philippinarum* with 3034 ind./m^2 in November, and *M. senhousia* with 223 ind./ m^2 in November (Yoon S.-P. *et al*., 2009). According to our study, the most frequently encountered species was *N. tenuis*, with 579 living specimens at 7 (out of 11) stations. Other frequently found species were *T. lubrica* (104 specimens, 8 stations), *A. ojianus* (81 specimens, 5 stations), *A. subquadrata* (46 specimens, 8 stations), *R. pulchella* (34 specimens, 5 stations), and *Y. notabilis* (27 specimens, 6 stations). Some of these species are common in muddy bottom communities in shallow embayments in Korea: *T. lubrica* in Masan, Aenggang, Yoja and Chinhae bays; *R. pulchella* in Masan and Chinhae bays; *A. ojianus* in Aenggang Bay and in the Gangneung area (see Table 3 in: Lutaenko *et al*. (2006)). *T. fragilis* is considered as indicative of organic pollution (Hong *et al*., 1994). In Chinhae Bay, two peaks of spat settlement were observed, one in summer and another in winter, with a maximum in summer; the population density is highest at the mouth of the bay, up to 2116 ind./m^2 in summer, but it rapidly declined in the fall after mass mortality (Lim *et al*., 1995). *T. lubrica* and *R. pulchella* are adapted to extreme environments and are often found on black deoxygenated mud where the bottom water lacks dissolved oxygen in the summer stagnation period (Habe, 1956). The formation of such populations exhibits a cyclic character, and juveniles are recruited several times during the stratification period. *T. fragilis* is a short-lived species; however, in the Seto Inland Sea most of the juveniles found at hypoxic stations died out immediately after settlement and never grew to the adult size (Kagawa, 1986). In Hakata Bay, northern Kyushu, the spatial dynamics of populations of *T. fragilis* and *M. senhousia* can differ greatly depending on the season. The center of mollusk distribution shifts from the inner waters of the bay to the central waters during the summer stratification period when dissolved oxygen of the bottom water diminishes; the center returns to the inner waters when dissolved oxygen increases (Hamano *et al*., 1986). In the northern East Sea, *T. fragilis* plays a significant role in soft-bottom communities of semi-enclosed inlets in Possjet Bay with a density of up to 140 ind./m^2 (Golikov and Scarlato, 1967), and is also very abundant in muddy substrate in the innermost parts of Amursky and Nakhodka Bays (Lutaenko, 1999; 2003).

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Explanations of Plates

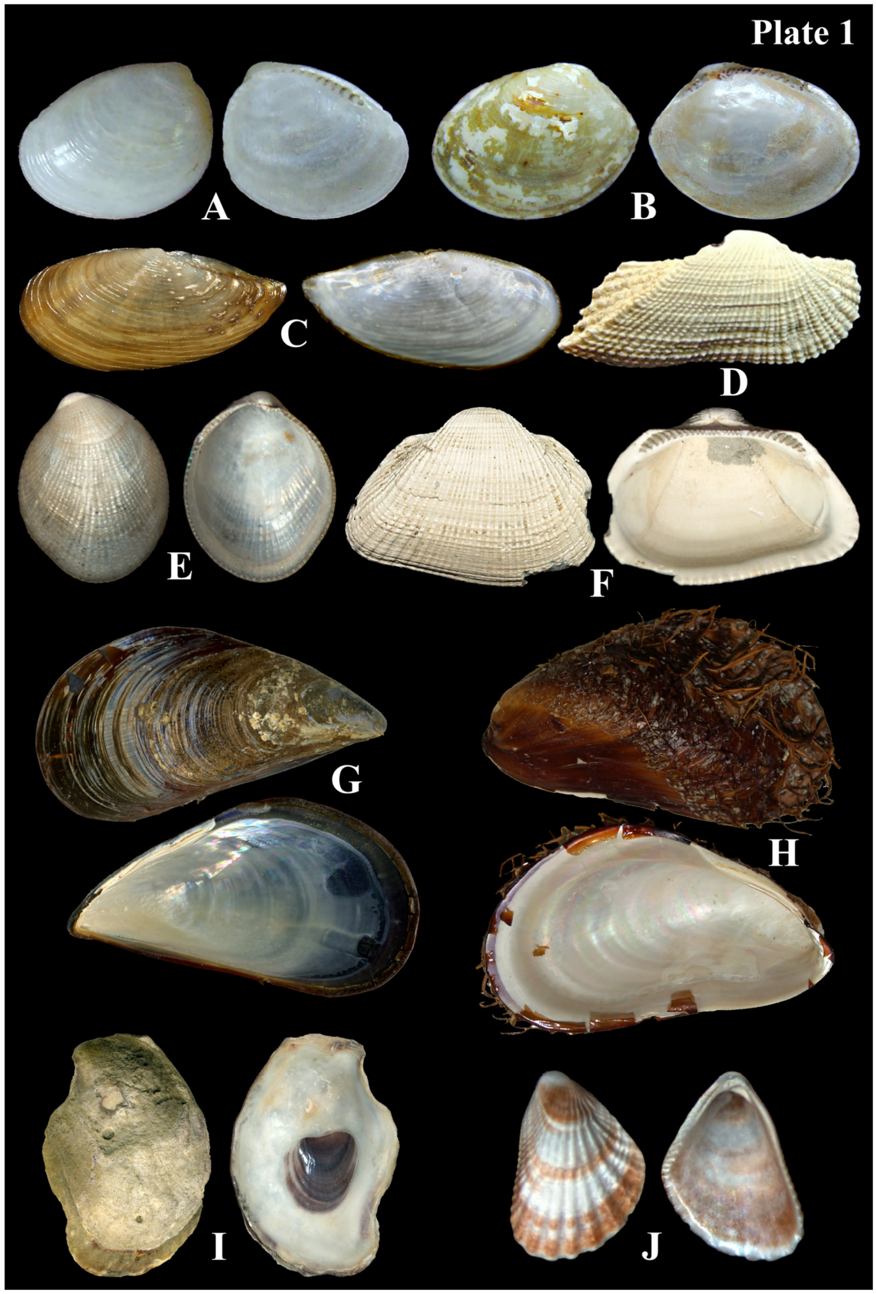

Plate 1. A - *Nucula* (*Nucula*) *paulula* A. Adams, 1856: Ulsan Bay, sta. 3, depth 15 m, shell length 3 mm, ZMFU no. 37732/Bv-5500; **B** - *Nucula* (*Leionucula*) *tenuis* (Montagu, 1808): Ulsan Bay, sta. 5, depth 43 m, shell length 3 mm, ZMFU no. 37721/Bv-5489; **C** - *Yoldia* (*Cnesterium*) *notabilis* Yokoyama, 1922: Ulsan Bay, sta. 6, depth 55 m, shell length 32.0 mm, ZMFU no. 26572/Bv-4487; **D** - *Arca boucardi* Jousseaume, 1894: Ulsan Bay, sta. 5, depth 43 m, shell length 4.0 mm, ZMFU no. 37691/Bv-5462; **E** - *Crenella decussata* (Montagu, 1808): Ulsan Bay, sta. 5, depth 43 m, shell length 3.5 mm, ZMFU no. 37966/Bv-5643; **F** - *Striarca symmetrica* (Reeve, 1844): Ulsan Bay, sta. 10, depth 22 m, shell length 11.7 mm, ZMFU no. 26560/Bv-4475; **G** - *Mytilus* (*Mytilus*) *galloprovincialis* Lamarck, 1819: Ulsan Bay, sta. 11, depth 1-3 m, shell length 54.1 mm, ZMFU no. 26566/Bv-4481; **H** - *Modiolus* (*Modiolus*) *kurilensis* Bernard, 1983: Ulsan Bay, sta. 11, depth 1-3 m, shell length 25.5 mm, ZMFU no. 26567/Bv-4482; **I** - *Crassostrea gigas* (Thunberg, 1793): Ulsan Bay, sta. 5, depth 43 m, shell height 30.0 mm, ZMFU no. 26568/Bv-4483; **J** - *Septifer* (*Mytilisepta*) *virgatus* (Wiegmann, 1837): Ulsan Bay, sta. 3, depth 15 m, shell length 3.4 mm, ZMFU no. 37965/Bv-5642.

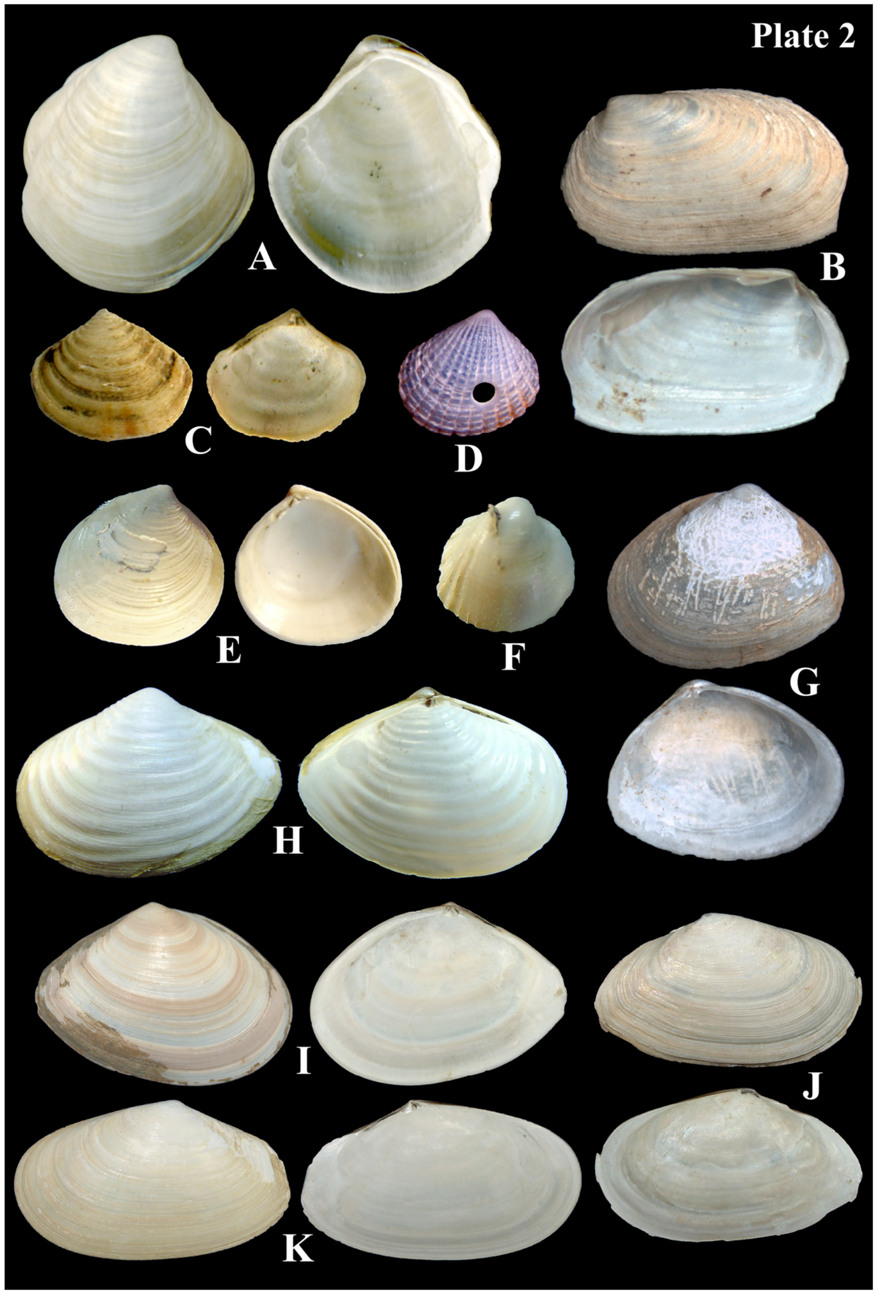

Plate 2. **A** - *Thyasira tokunagai* Kuroda et Habe, 1951: Ulsan Bay, sta. 10, depth 22 m, shell length 6.8 mm, ZMFU no. 26575/Bv-4490; **B** - *Nipponomysella oblongata* (Yokoyama, 1922): Ulsan Bay, sta. 10, depth 22 m, shell length 5.4 mm, ZMFU no. 37963/Bv-5640; **C** - *Salaputium* cf. *unicum* Hayami et Kase, 1993-: Ulsan Bay, sta. 5, depth 43 m, shell length 3.5 mm, ZMFU no. 26559/Bv-4474-; **D** - *Carditellopsis toneana* (Yokoyama, 1922): Ulsan Bay, sta. 3, depth 15 m, shell length 2.0 mm, ZMFU no. 37748/Bv-5516; **E** - *Alveinus ojianus* (Yokoyama, 1927): Ulsan Bay, sta. 10, depth 22 m, shell length 3.0 mm, ZMFU no. 37745/Bv-5513; **F** - *Fulvia hungerfordi* (G.B. Sowerby III, 1901): Ulsan Bay, sta. 10, depth 22 m, shell length 2.0 mm, ZMFU no. 37690/Bv-5461; **G** - *Macoma* (*Macoma*) *incongrua* (Martens, 1865): Ulsan Bay, sta. 5, depth 43 m, shell length 8.0 mm, ZMFU no. 37724/Bv-5492; **H** - *Raeta* (*Raetellops*) *pulchella* (Adams et Reeve, 1850): Ulsan Bay, sta. 5, depth 43 m, shell length 19.7 mm, ZMFU no. 26562/Bv-4477; **I** - *Macoma* (*Macoma*) *tokyoensis* Makiyama, 1927: Ulsan Bay, sta. 5, depth 43 m, shell length 27.5 mm, ZMFU no. 26565/Bv-4480; **J** - *Moerella iridescens* (Benson, 1842): Ulsan Bay, sta. 5, depth 43 m, shell length 28.7 mm, ZMFU no. 26574/Bv-4489; **K** - *Angulus vestalioides* (Yokoyama, 1920): Ulsan Bay, sta. 10, depth 22 m, shell length 24.5 mm, ZMFU no. 26573/Bv-4488.

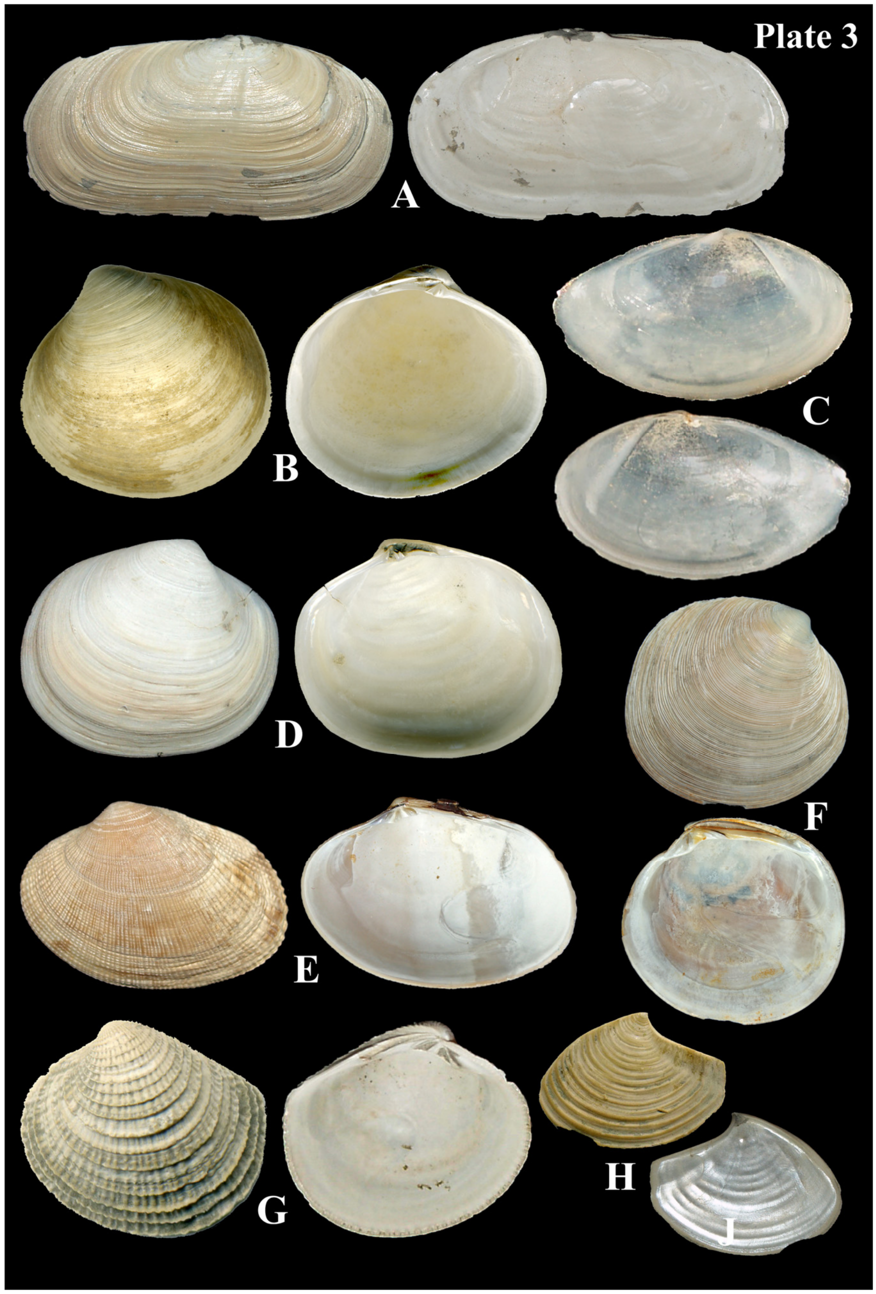

Plate 3. **A** - *Azorinus abbreviatus* (Gould, 1861): Ulsan Bay, sta. 10, depth 22 m, shell length 28.9 mm, ZMFU no. 26569/Bv-4484; **B** - *Cycladicama cumingii* (Hanley, 1844): Ulsan Bay, sta. 10, depth 22 m, shell length 33.3 mm, ZMFU 26571/Bv-4486; **C** - *Theora* (*Endopleura*) *lubrica* A.A. Gould, 1861: Ulsan Bay, sta. 2, depth 15 m, shell length 11.2 mm, ZMFU no. 26564/Bv-4479; **D** - *Cycladicama* cf. *lunaris* (Yokoyama, 1927): Ulsan Bay, sta. 9, depth 34 m, shell length 13.7 mm, ZMFU no. 26570/Bv-4485; **E** - *Ruditapes philippinarum* (A. Adams et Reeve, 1850): Ulsan Bay, sta. 11, depth 1-3 m, shell length 21.6 mm, ZMFU no. 26558/Bv-4473; **F** - *Dosinia* (*Dosinella*) *penicillata* (Reeve, 1850): Ulsan Bay, sta. 5, depth 43 m, shell length 46.7 mm, ZMFU no. 26557/Bv-4472; **G** - *Protothaca* (*Protocallithaca*) *adamsii* (Reeve, 1863): Ulsan Bay, sta. 10, depth 22 m, shell length 8.5 mm, ZMFU no. 26563/Bv-4478; **H** - *Myadora japonica* Habe, 1950: Ulsan Bay, sta. 5, depth 43 m, shell length 14.3 mm, ZMFU no. 26561/Bv-4476.