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Invasion of the North American Wedge Clam *Rangia cuneata* (G.B. Sowerby I, 1831) (Bivalvia: Mactridae) in the Vistula Lagoon of the Baltic Sea

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Abstract—North American brackish water bivalve *Rangia cuneata* (G.B. Sowerby I, 1831) was recorded for the first time in the Vistula Lagoon of the Baltic Sea in September 2010. On the basis of features of its biology, we assume that the invasion of this species into the Vistula Lagoon took place at least 2–3 years earlier, in 2007–2008. In 2010–2011, *R. cuneata* colonized and inhabited a large area of the bay. The maximum abundance (up to 4040 ind./m^2) was observed in the areas adjacent to the Kaliningrad sea channel. Most likely, the invasion of *R. cuneata* into the Vistula Lagoon is related to the ballast waters of ships, including dredging ships, which came from areas where the clams are already naturalized. The naturalization of *R. cuneata* poses a threat of new serious transformations in the ecosystem of the Vistula Lagoon. The invasion requires increased monitoring of the state of its benthic communities.

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Keywords: *Rangia cuneata*, Bivalvia, invasion, distribution, Vistula Lagoon, Baltic Sea

INTRODUCTION

Intense human activity facilitates the successful spread and naturalization of many species of aquatic organisms in new habitats with similar environmental conditions (including coastal waters). In some cases, such invasions result in noticeable changes in the recipient systems (*Biologicheskie invazii*..., 2004). The Baltic Sea is not an exception in this respect. During the last 30 years, 36 invasive species were found in the sea basin with 22 species naturalized in these waters (*Baltic Sea Alien Species Database*, 2007). As one of the examples of invasions that triggered various changes in the Baltic Sea ecosystem is the invasion of North American polychaete *Marenzelleria neglecta* Sikorski and Bick, 2004. In the mid-1980s, this species was transported with ballast waters to the Baltic Sea and successfully naturalized there (Bick and Burckhardt, 1989; Gusev and Starikova, 2005; Warzocha et al., 2005; Kotta et al., 2006; Maksimov, 2010; etc.). In 1988, along with increased water salinity, the introduction of *M. neglecta* in the Vistula Lagoon took place. The expansion of this species changed the structure of the established indigenous bottom community. In particular, the aboriginal freshwater species were forced out of the greater part of the area of the water body, which resulted in the temporary replacement of the dominant freshwater species, *Chironomus plumosus* (Linnaeus, 1758), by brackish water *M. neglecta* (Rudinskaya, 1999, 2000).

Discovery of the North American wedge clam *Rangia cuneata* in the Vistula Lagoon represents a new stage of invasions which may trigger new serious transformations of the local benthic communities. In consideration of this, the main goals of the present paper are to assess the dynamics of the spatial distribution and size structure of the *R. cuneata* population, to describe possible ways of invasion, and to analyze environmental conditions in the natural range of the Atlantic rangia in comparison with the conditions in the Vistula Lagoon.

MATERIALS AND METHODS

Study area. The Vistula (Kaliningrad) Lagoon is situated in the southeastern part of the Baltic Sea (Fig. 1). It is separated from the Gulf of Gdansk by the Vistula Spit and is connected to the Baltic Sea by a narrow navigable strait having the width of 400 m and depth of 10–12 m. The area of the lagoon is 838 km^2, of which 472.5 km^2 belong to the Russian Federation. The volume of the lagoon depression is 2.3 km^3. The total annual drainage from the bay to the sea averages 20.5 km^3; the total annual inflow is 17.0 km^3, accounting for 88.5% of the total water balance. The average depth is 3.1 m, and the maximum depth is 5.2 m. The water salinity fluctuates during the year from 0.1 to 8‰, averaging 3.7‰ (Silich, 1971; Berenbeym, 1992). The mean monthly temperature of the surface water layer

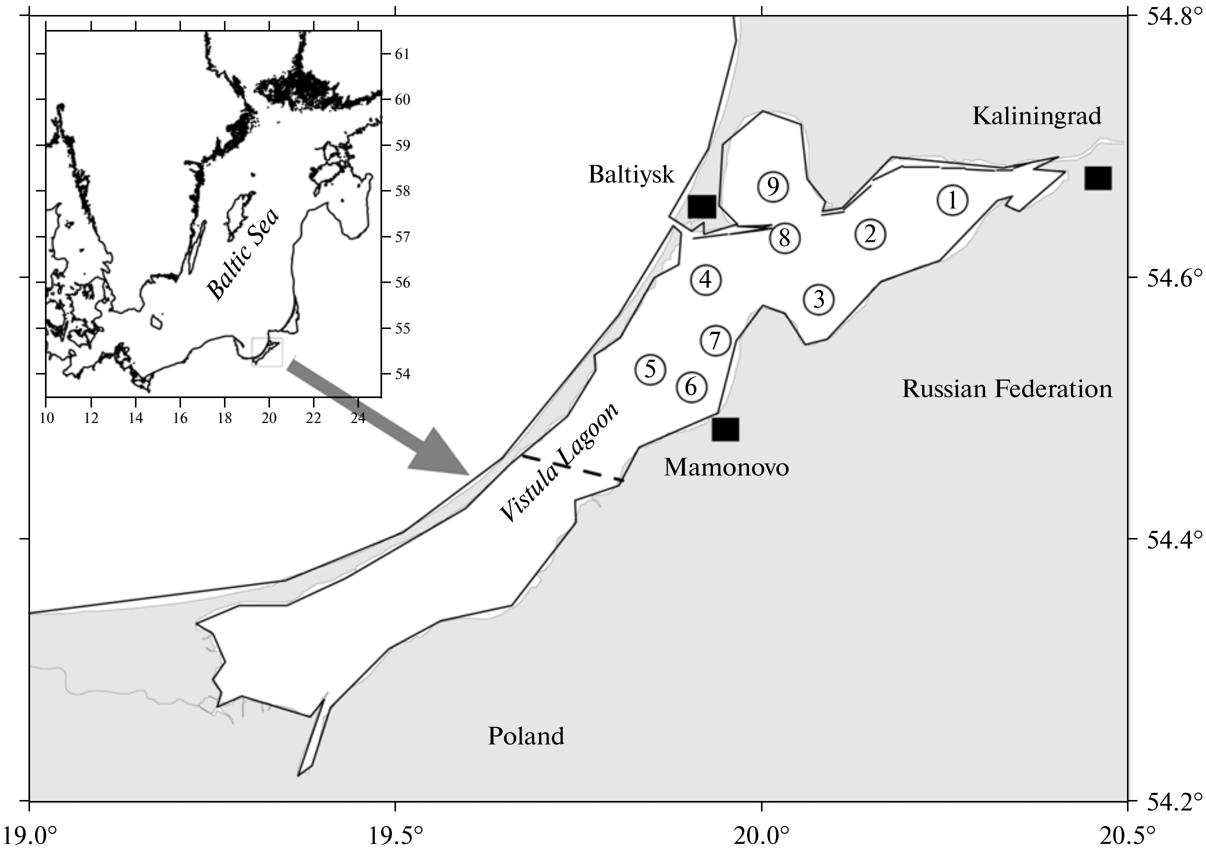

Fig. 1. Schematic map of locations of sampling sites in the Vistula Lagoon.

changes from 0.2°C in February to 21.2°C in July. The water transparency is low, 0.5–0.7 m, which is determined by high turbidity owing to both natural (shallow waters, wind-driven waves, riverine flux, etc.) and intense anthropogenic impact (Senin et al., 2004). The content of suspended matter is distributed unevenly over the bay area and is ten times higher than in the Baltic Sea (Chechko, 2002). The oxygen content in the summertime does not drop down below 9.8 mg/L (Senin et al., 2004). The grounds are predominantly silty and silty-sandy (Chechko and Blazhchishin, 2002).

Sampling and analysis of samples. The samples of macrozoobenthos collected in the open part of the Vistula Lagoon served as the material for the present study. The sampling was performed within the framework of annual monitoring on the network of standard sampling stations (Fig. 1). The sampling was performed using a Petersen bottom sampler with a sampling area of 0.025 m^2 and presumed depth of penetration into the ground of 10–15 cm. The samples were washed through a sieve with 0.5 mm mesh size aboard the research vessel and then preserved in 4% formalin (Salazkin et al., 1983; *Rukovodstvo...*, 1983). The clams were counted and the individual shell lengths were measured (Fig. 2a).

Identification. The identification of *R. cuneata* was difficult since in autumn 2010 only young specimens having poorly developed taxonomic features (e.g., insufficiently massive shell, specificity of the bend of the shell top bent inside and shifted toward the front part of the shell) were sampled. The ligament in adult specimens has a specific maroon brown color (Figs. 2b and 2c). The pattern of the mantle sinus and cross striation of the lateral dents has signs of ontogenetic variability. The tilt and position of the shell tops clearly indicated that these mollusks differ from the common bivalves in the Vistula Lagoon (*Macoma balthica* (Linnaeus, 1758), *Cerastoderma glaucum* (Poiret, 1789), and *Mya arenaria* (Linnaeus, 1758). This is why we assumed that a new bivalve species not recorded earlier in the Vistula Lagoon and Baltic Sea was found. The first collected specimens resembled coastal Atlantic mollusks of genus *Spisula* (Gray, 1837), but the representatives of this genus do not inhabit brackish waters. Large specimens (34.1 and 35.2 mm) sampled in June 2011 already had solid shells with typically bent shell top and clear mantle sinus. The species of genus *Spisula* lack both of the above features. This is why the sampled bivalves were attributed to fam. Mactridae. However, these were not the European species of this family. Our West European colleagues faced similar problems in the first registration of *R. cuneata* in Euro-

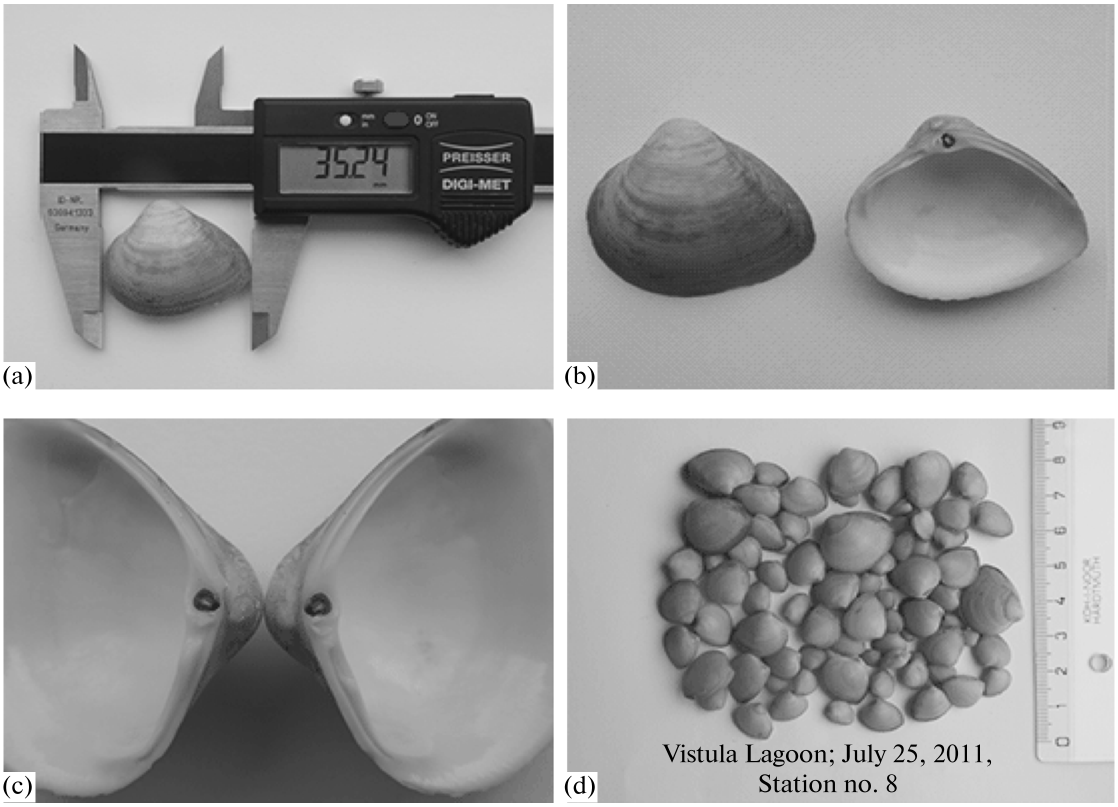

Fig. 2. Vistula Lagoon *Rangia cuneta*: (a) maximum shell length, mm; (b) side and inside views; (c) shell lock and internal ligament; (d) the clams sampled on July 25, 2011, at station no. 8.

pean waters. The *R. cuneata* were exactly identified using the identification key developed for modern European representatives of fam. Mactridae (Verween et al., 2006).

RESULTS

Dynamics of registration and quantitative parameters of *R. cuneata*. In September 2010 at five sampling stations in the central part of the Vistula Lagoon, the *Rangia cuneata* was found for the first time (Fig. 3). Its abundance varied from 80 to 920 ind./m^2 (maximum at station no. 8), averaging 144 ind./m^2. In October, the range of *R. cuneata* expanded to the south of the bay. It was already recorded at seven stations with the mean abundance of 552 ind./m^2, with maximum abundance on record for the whole observation period of 4040 ind./m^2 (also at station no. 8). In spring 2011, the area on which *R. cuneata* was recorded declined compared to the fall observations (Fig. 4). The mean abundance in April was 119 ind./m^2; in May, 94 ind./m^2. In June, the range of the clams recovered to the previous borders and they were found to the west (station no. 2). The abundance of Atlantic rangia for the whole bay in June and July averaged 684 and 691 ind./m^2, respectively. However, in June, the maximum abundance of 2960 ind./m^2 was recorded at station no. 9; at station no. 8, it was 1120 ind./m^2. In July, the maximum abundance was recorded again at station no. 8 (3120 ind./m^2); at station no. 9, it was 2080 ind./m^2.

Size structure of *R. cuneata*. In September 2010, the length of the clam ranged 2–10 mm; in October 2010, 1–14 mm with modal shell size of 2–4 mm (Fig. 5). After wintering, in April and May 2011, the shell lengths varied from 3 to 11 mm, with modal shell size of 4 mm in April and 3–4 mm in May. In June 2011, *R. cuneata* had a shell length of 1–16 mm and solitary specimens with lengths of 19.3, 34.1, and 35.2 mm were found. In July 2011, the size range increased to 21 mm (solitary specimens had lengths of 24.0 and 28.4 mm). In June 2011, the modal lengths were formed by clams with shell lengths of 4–5 mm; in July, 9–10 mm.

DISCUSSION

Growth and age. *Rangia cuneata* is a North American brackish water wedge clam. From September 2010 through May 2011 in the Vistula Lagoon, only specimens of the first year of life with shell lengths of 1–14 mm were found. In June and July, specimens with shell longer than 20 mm were recorded, with their age

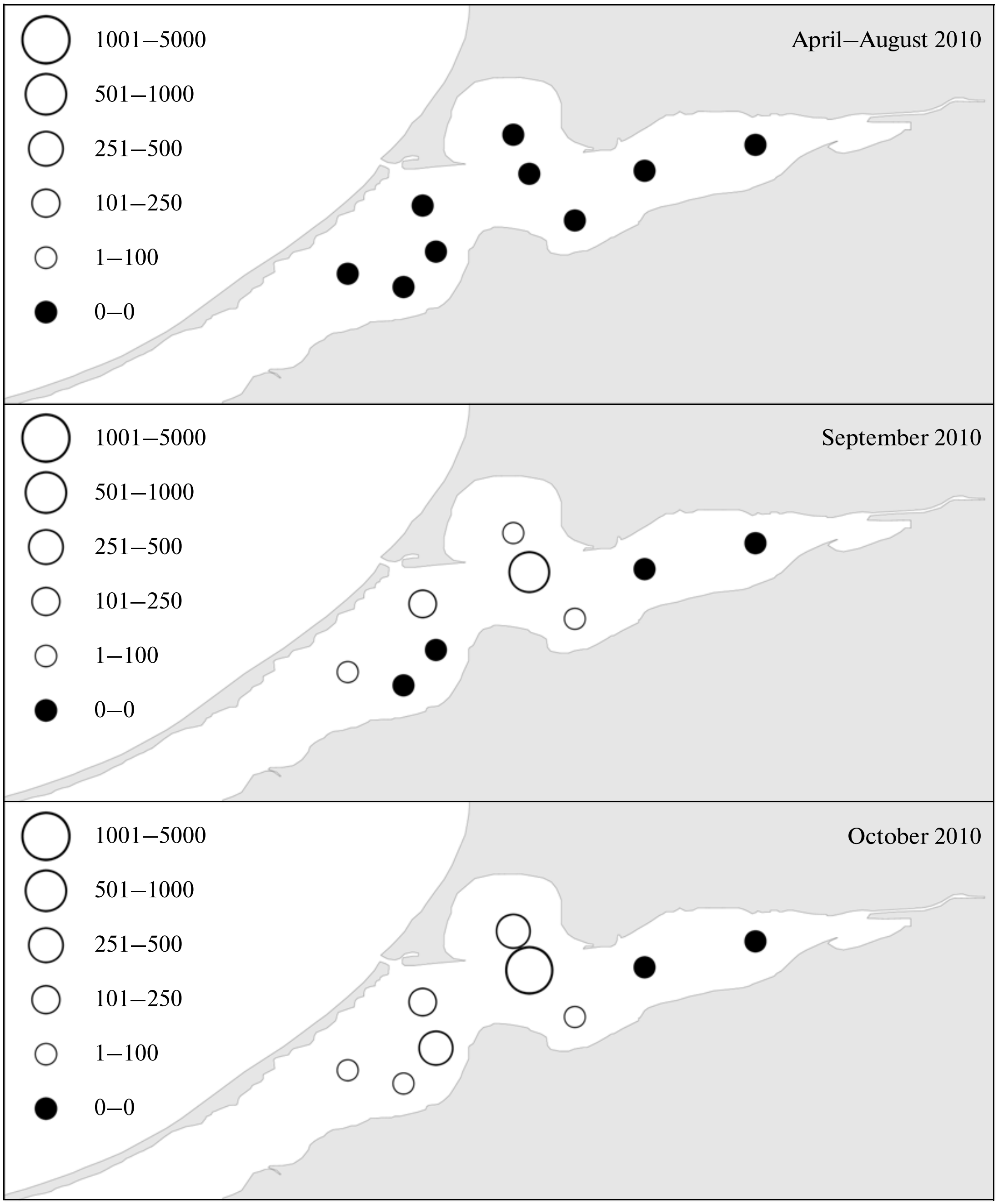

Fig. 3. Distribution of *Rangia cuneata* in the Vistula Lagoon in 2010.

corresponding approximately to 2 to 4 years of life. In the North American coastal waters, the Atlantic rangia reaches lengths of 60–94 mm and has a fast growth rate, reaching 15–20 mm during the first year of life (Fairbanks, 1963; Wolfe and Petteway, 1968; Hoese, 1973; LaSalle and de la Cruz, 1985). In European waters, the maximum recorded shell length is 40 mm (Verween et al., 2006). The histogram of the size composition of the population (Fig. 5) indicates that first annual ring in the specimens that settled in September–October 2010 was formed at the shell length of 3–11 mm. In the Vistula Lagoon, as in North American waters, *R. cuneata* grows quite fast and may gain approximately 10 mm or more in one year. In North America, the maximum age of *R. cuneata* is 12 years (Wolfe and Petteway, 1968); in Europe, 6 years (Kerckhof et al., 2007). Off the coast of Louisiana, *R. cuneata* maturates at the shell length of 24 mm or more (Fairbanks, 1963); off the coast of Virginia, 14 mm (Cain, 1972), which corresponds to the age of 2–3 years (Fairbanks, 1963; Wolfe and Petteway, 1968; Cain, 1972).

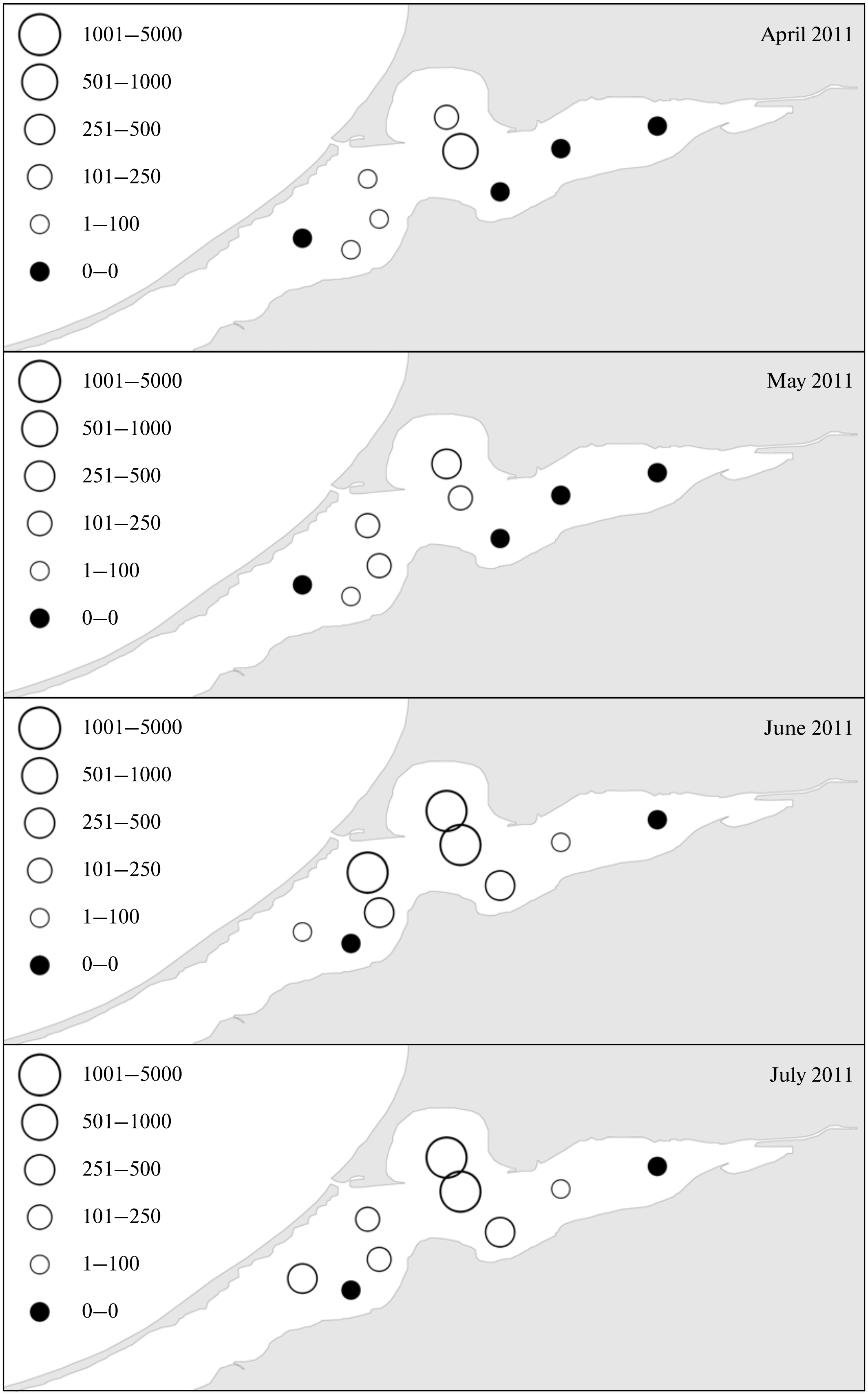

Fig. 4. Distribution of *Rangia cuneata* in the Vistula Lagoon in 2011.

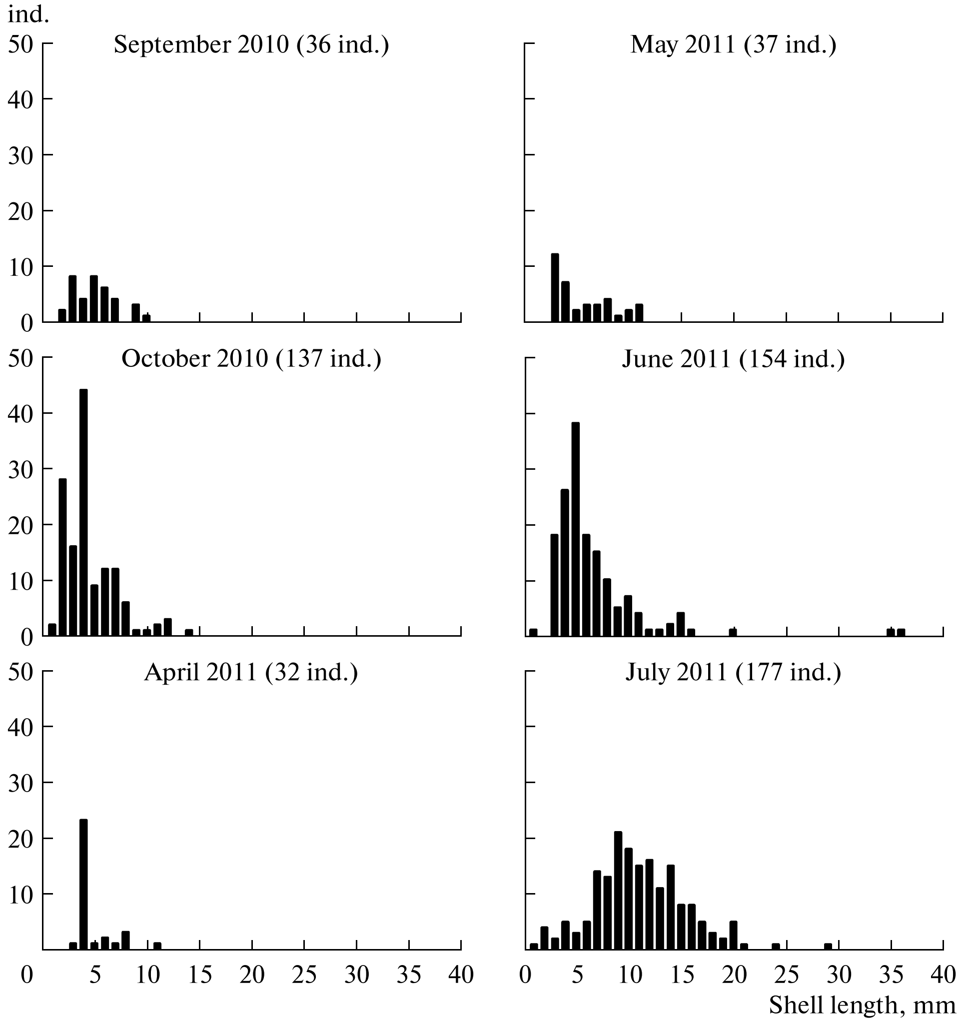

Fig. 5. Size composition of *Rangia cuneata* colonies in the Vistula Lagoon in 2010–2011.

Reproduction and sexual structure. Two peaks of abundance of juvenile Atlantic rangia were recorded in the Vistula Lagoon: in September–October 2010 and in June–July 2010 (Fig. 5). Off the coast of Louisiana, *R. cuneata* reproduces in March–May and from the end of summer through November (Fairbanks, 1963); off the coasts of Mexico, in February–June and in September–November (Rogers and Garsia-Cubas, 1981). In favorable conditions, reproduction may take place all year-round. Cain (1975) revealed that the gametogenesis in *R. cuneata* starts when the water temperature reaches 15°C or higher and the water salinity is within the range of 0‰ to 15‰ (Hopkins, 1970). Presumably, the reproduction of *R. cuneata* in the Vistula Lagoon starts at the end of May when the mean water temperatures reaches 15°C and continues until October (Senin et al., 2004). The usual ratio of sexes is 1 : 1 (Fairbanks, 1963; Rogers and Garsia-Cubas, 1981), but sometimes females prevail (Cain, 1972). Hermaphrodite specimens among *R. cuneata* were found to account for 0.1–2.1% in the population (Olsen, 1976b; Rogers and Garsia-Cubas, 1981). We did not find any data on fertility of *R. cuneata* in the available literature.

Characteristics of the environment. The combination of low water salinity, high turbidity, and the presence of a soft substrate composed of sand, silt, and vegetation creates the most favorable conditions for *R. cuneata* (Tarver, 1972). The clams live at water salinity of 0–18‰. The maximum abundance and number of size classes are observed at even lower salinity of 0–2‰ (Hoese, 1973; etc.). Low temperature in winter negatively influences the survival of *R. cuneata* (Gallagher and Wells, 1969). The specimens of this species are not mobile (Fairbanks, 1963) but are able to move vertically in the ground column (Sikora et al., 1981). The available literature lacks data on the vertical distribution of *R. cuneata* in bottom sediments. Possibly, the decrease in the area where the clams were found in spring 2011 was related both to the severe winter and to the possibility for the clams to bury themselves in the ground for wintering. Consequently, the clams may not have been sampled with the utilized model of sampler. The clams are able to tolerate oxygen deficiency but are very intolerable to drying (Chen and Awapara, 1969; Olsen, 1976b). The adult specimens prefer soft substrata at depths of less than 6 m (Fairbanks, 1963; Tarver, 1972; Hoese, 1973; Cain, 1975; Jordan and Sutton, 1984). All facts given above explain why *R. cuneata* found appropriate conditions (see study region) for survival and successful naturalization in the Vistula Lagoon. The relatively high dynamics of the bay waters (Silich, 1971, Berenbeym, 1992; Chechko, 2002; Chechko and Blazhchishin, 2002; Senin et al., 2004) facilitated the fast spread of the clams.

The embryos are more susceptible and are unable to develop in fresh water. Water temperature of 18–29°C and salinity of 6–10‰ are optimal for their development. The larvae are able to live at temperatures of 8–32°C and water salinity of 2–20‰ (Cain, 1973). The survival rate in larvae decreases at the combinations of two factors: low salinity and high temperature or high salinity and low temperature (Cain, 1973). The larvae prefer firm substrata, but this is not a necessary condition for settling of larvae and metamorphosis (Sundberg and Kennedy, 1992).

Feeding. By the feeding mode, *R. cuneata* is a nonselective filter feeder. The clams consume large amounts of detritus and phytoplankton (Darnell, 1958). Darnell (1958) noted that the digestive tract contained 70% detritus, 10% sand, and 17% algae (possibly of genus *Anabaena* Bory de Saint-Vincent ex Bornet & Flahault, 1886 or *Microcystis* Lammermann, 1907), as well as diatoms, foraminifera, and remnants of vascular plants. Olsen (1976a) identified 48 species of phytoplankton in the stomach of *R. cuneata*; detritus accounted for 46–81% of the stomach content. Tenore et al. (1968) suggested that Atlantic rangia may swallow organic matter either directly from the sediments or consuming bacteria. Thus, wedge clam is an important ecological link in the estuarine food chain.

The zoobenthos of the open part of the Vistula Lagoon is qualitatively poor. The bay is inhabited by euryhaline marine and freshwater species as well as brackish water species adapted to the variable water salinity. Midge larvae *Chironomus plumosus* dominate the bay macrozoobenthos. The zoobenthos of the open part is represented mainly by four large taxa: chironomids, oligochaetes, polychaetes, and mollusks. This is why the bottom communities consist of a small number of species. By the type of feeding in the open part of the bay, detritivores dominate (78%), followed by ground feeders (14%), phytivores (5%), filter feeders (2%), and predators (about 1%) (Rudinskaya, unpublished data).

We presume that the lack of competitors for food over most of the Vistula Lagoon and the low salinity threshold for development of the larvae provide *R. cuneata* with ability to colonize larger areas in the bay compared to bivalves of marine (*Macoma balthica* (Linnaeus, 1758) and *Mya arenaria* (Linnaeus, 1758)), brackish water (*Cerastoderma glaucum* (Poiret, 1789)), and freshwater (*Pisidium amnicum* (O.F. Müller, 1774) and *Sphaerium corneum* (Linnaeus, 1758)) origins.

Distribution and invasion dynamics. It is commonly accepted now that the Gulf of Mexico is the historic range of *R. cuneata*. At the end of the 1960s, the clam was introduced with ballast waters to the Northwest Atlantic, where it inhabits mostly estuaries and river mouths. In August 2005, *R. cuneata* was found for the first time in the Antwerp harbor (Verween et al., 2006). It is suggested that it penetrated there earlier, approximately in 2000 (Kerckhof et al., 2007). In June 2008, *R. cuneata* was found in the canals of Amsterdam (Melchers and Moolenbeek, 2008). In September 2010, its mass appearance was recorded in the Vistula Lagoon of the Baltic Sea, where the densest colonies of the clam were revealed at stations nos. 8 and 9 (Figs. 3 and 4). The peculiar features of the biology of *R. cuneata* suggest that its introduction into the bay took place at least two to three years earlier, approximately in 2007–2008. We expect that, after the generation of 2010 reaches the age of two years (the age of sexual maturity), Atlantic rangia will form high-density colonies in the regions where it was established and will also occupy new habitats. The most probable way of penetration of *R. cuneata* into the Vistula Lagoon is related both to ships' ballast waters and to the activity of dredges deepening the waterway in the Kaliningrad sea canal. These vessels may have transported the clam from the North Sea, visited by ships earlier and where populations of Atlantic rangia were already established (in 2008, dredging was started in the Kaliningrad harbor and was performed by Dutch vessels) (Verween et al., 2006; Melchers and Moolenbeek, 2008). The above suggestion is substantiated by the fact that, at the most freshwater station no. 2, only large clams with shell lengths of 28.4 and 35.2 mm were found and the abundance of Atlantic rangia at this location was minimal (40 ind./m^2).

It is still unclear whether these clams are present in the Baltic Sea. However, the high abundance of *R. cuneata* in the Vistula Lagoon near the Kaliningrad sea channel suggests the high probability that Atlantic rangia already penetrated into the Baltic Sea.

Ecological importance. Poor competitiveness and active pressure of predators determine the low abundance of wedge clam in conditions of high water salinity within the natural range (Cooper, 1981). The ash-free caloric content of soft tissues of *R. cuneata* ranges from 3.5 to 5.2 kcal/g (Lane, 1986). This is why that, in the estuarine ecosystems, it is an important food source for fish, crabs, gastropods, ducks, and ctenophores (LaSalle and de la Cruz, 1985). Since low mobility is a characteristic of the mollusk, their shells may serve as a substrate for epifaunal organisms (Hoese, 1973).

The gonads of *R. cuneata* may be parasitized by larvae of trematodes of fam. Fellodistomatidae (Fairbanks, 1963), which potentially cause castration of the clams (Wardle, 1983). The surfaces of gill and gonads are inhabited by the ciliate *Ancistrum mytili* (Quennerstedt, 1867); the epithelium of foot and adjacent parts of the body are inhabited by the ciliate *Peniculistoma mytili* (De Morgan, 1925) Jankowski, 1964 and by parasites of the mussel *Mytilus edulis* Linnaeus, 1758 (Gaevskaya, 2006). This poses a threat of introduction of new parasite species associated with invasion of Atlantic rangia. The consequences of this event for the aboriginal species in the recipient water bodies are unpredictable.

Commercial importance. Buried tanatocenoses of *R. cuneata* are used for production of materials for construction of roads, for production of some chemicals, for agricultural lime, and as a source of calcium carbonate and food additives to the feed for poultry and livestock (Tarver and Dugas, 1973; Swingle and Bland, 1974; Arndt, 1976). In the United States and Mexico, *R. cuneata* is consumed as a seafood and canned (Woodburn, 1962; Pfitzenmeyer and Drobeck, 1964; Wass and Haven, 1970) and is used as bait for catching blue crabs (Godcharles and Jaap, 1973).

CONCLUSIONS

The invasion of *R. cuneata* and its rapid spread in the Vistula Lagoon necessitate further studies of the species ecology since it is possible that, in the near future, Atlantic rangia may settle over the whole bay and appear in the Baltic coastal waters. It is not possible to predict the exact consequences of invasion of *R. cuneata* into the Vistula Lagoon, but it is likely that several consequences of this invasion may be positive: increased biofiltration, which may affect water "self-purification" and improvement (first of all, owing to juvenile clams) of food stocks for benthivorous fish and waterfowl. On the other hand, the clam invasion-driven changes in the environmental conditions may result in the change of the dominant taxon and in the structure of benthic community. In the future, it may result in the domination of a grazing food chain over the detrital one in the Vistula Lagoon ecosystem. Establishment of Atlantic rangia may result in appearance of new diseases and parasites and possibly blocking of the water inlets.

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