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Distribution of sand hoppers (*Talitrus saltator*, Montagu, 1808) on the beach of the Lithuanian Baltic Sea

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Talitrus saltator was collected on the Smiltynė beach of the Baltic Sea beside the Curonian Spit in the period 01 07 2005–30 09 2005, taking samples once a week every 1 m from the shoreline to the beginning of dunes. On sand, a frame (0.5 × 0.5 m) was put, and sand hoppers were collected and fixed with 70% ethanol. The highest density of adult *Talitrus saltator* individuals was found within 4–6 m, of juveniles within 6–5 m, of females 4–6 m and males 4–7 m. The lowest density values were defined beyond the 10th meter from the shoreline up to the dunes. The density of sand hoppers was highest in the middle of September and the lowest in the second half of August. The highest density of adults was fixed in the middle of August and the lowest in the first half of July. The highest density of juveniles was defined in the first part of July and the lowest at the end of the period of reproductive performance, i. e. in the second half of September. The highest values of male and female density were fixed in August–September. The greatest population biomass was defined at the end of July when the density of population individuals was one of the greatest. When juveniles dominated in the population (beginning of July), the least biomass was fixed. The greatest biomass on the beach was established within 4 and 6 meters from the shoreline. The one-factor dispersion analysis (ANOVA) and Pearson's correlation between the parameters of environment (air and water temperature, intensity of swell, wind speed) and the density / biomass of individuals was estimated. Evaluation of a possible influence of the environmental factors (air and water temperatures, intensity of swell and wind speed) on the density of sand hoppers during the study period revealed no significant correlation between these parameters.

Key words: beach of the Baltic Sea, *Talitrus saltator,* density, biomass

INTRODUCTION

Talitrus saltator is a sand hopper whose expansion area includes the north-eastern part of the Atlantic Ocean and sandy beaches of the North, Baltic and Mediterranean seas (Fuentes, 2004). The wide borders of sand hoppers' expansion allow characterizing them as inhabitants of the largest part of European beaches (Brown, McLachlan, 1990). On the beach of the Baltic Sea in Poland, three species of sand hoppers have been found (*Orchestia cavimana, Talorchestia deshayesi* and *Talitrus saltator*), but *T. saltator* is found most frequently and shows the highest density (Jażdżewski, Konopacka, 1995; Spicer, Janas, 2006). Most frequently they are found under / between sediments, rotting marine algae, in zones of ebbs and flows, can be buried in substratum at a depth of 10–30 cm (Budd, 2004) and in winter even at a depth of 50 cm (Fuentes, 2004).

Sand hoppers are one of the main groups of beach inhabitants. It is an important part of energy exchange between many trophic levels (Fuentes, 2004; Lakkis, 2005). Sand hoppers are one of the main components in the diet of birds feeding on the coast. This group of animals helps to assess the ecological state of beaches (Jędrzejczak et al., 1999; Jędrzejczak, 2004). Little is known about talitrids from the Lithuanian coast. The aim of the present study was to define the spatial distribution and temporal population characteristics (density, biomass, ratio of males, females and juveniles) of sand hoppers (*Talitrus saltator*) on the beach of the Baltic Sea in Lithuania along the Curonian Spit.

MATERIALS AND METHODS

Samples were collected weekly in July, August and September of 2005 on the Smiltynė beach of the Baltic Sea along the Curonian Spit in line (shore-dune) every 1 m from the shoreline to the beginning of dunes (Fig. 1). In these places the coast is

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sandy; the lagoon and boden shores prevail. On sand, a frame (0.5 × 0.5 m) was put, and from this place sand hoppers were collected. Sand hoppers from each area were collected to different glassware and fixed with 70% ethanol.

While collecting the samples, the air temperature was taken. Data on water temperature, wind speed and the intensity of swell were submitted by the Center of Marine Research at the Ministry of Environment (Priekrantinių ..., 2005).

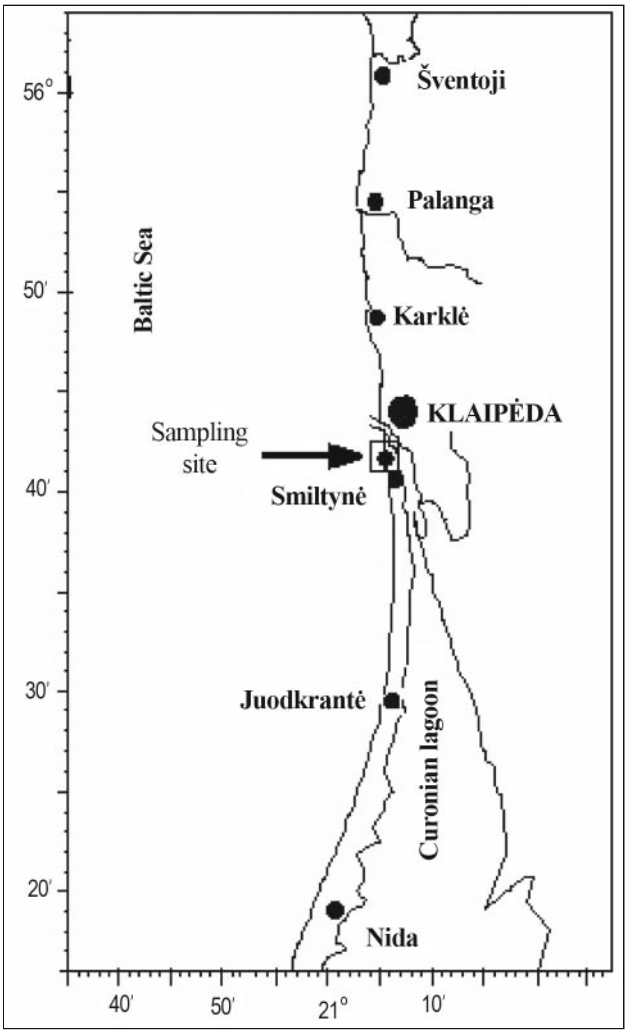

Fig. 1. Study area. Sampling site

In the laboratory, the examined individuals were described up to species (Köhn, Gosselck, 1989), measured (mm, error 0.05) from the rostrum to the beginning of hind legs (Budd, 2004), weighed (mg, error 0.01). The sex was defined by the first pair of forelegs which in males are larger and longer than in females (Budd, 2004).

By mathematical analysis of the data, the general, age and gender groups' density (ind. m^{-2}) and biomass (g m^{-2}) were calculated, evaluating their spatial distribution (shore–dune) and time distribution. For the analysis, data gained in the area of 1–12 m from the shoreline were used, because in the place left up to the dunes, during the time of sample collecting no individuals were found.

For the evaluation of individuals' density, one-factor dispersion analysis (ANOVA) was used to estimate the average density values, taking into account the interval values of one independent variable. When the places differed by two factors (intensity of swell and wind speed), two-factor dispersion analysis was used. This analysis permits to evaluate whether the means of dependent interval variables differ in different places and to ascertain the interaction of the independent factors. All sample pairs were compared by Fisher's LSD (Least Significant Difference) criterion, using t-criterion (when ANOVA shows that the difference of means is statistically significant). To evaluate the strength of variables' interdependency, Pearson's coefficient of linear correlation (r) was used.

RESULTS

Analysis of the spatial density of population (shore–dune)

The highest density of adults was defined in September, in the sixth meter from the shoreline (276 ind. m^{-2}) and in August in the ninth meter, while in July in the tenth–twelfth meters from the shoreline no adults were found. The greatest values of adults' density during all the period of study were defined within 4–6 m from the shoreline (Fig. 2).

The peak of juveniles' density in July was defined in the sixth meter from the shoreline (360 ind. m^{-2}), whereas within

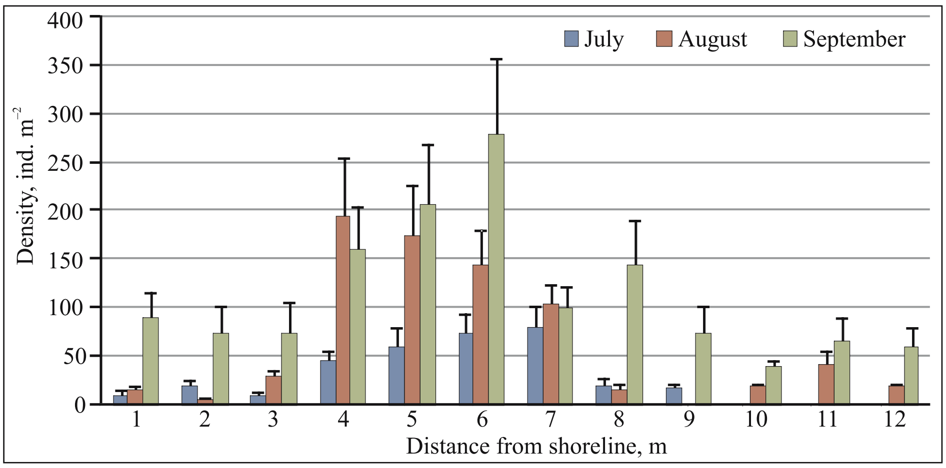

Fig. 2. Spatial (shore–dune) distribution of adult individuals

10–12 m no juveniles were found (Fig. 3). In August, the juvenile density was maximum in the fifth meter (104 ind. m^{-2}), and in the eighth-twelfth meters no individuals were found. In September, the density of juveniles was highest in the fourth meter (32 ind. m^{-2}), and in the twelfth meter no juveniles were found.

The density of females during all the period of research changed from absolute absence (in August in the first and ninth meters from the shoreline, in July in the tenth–twelfth meters) to 200 ind. m^{-2} (in September in the sixth meter from the shoreline) (Fig. 4). The highest density of females, as well as of adults, during the period of all three months was found in the fourth–sixth meters from the shoreline. The greatest density of males during all the period of research was defined in August in the fourth meter from the shoreline (96 ind. m^{-2}), and the values of density during all the study period were highest in the 4–7 meters (average value 45 ind. m^{-2}). In July in the first and third meters and in August in the ninth meter from the shoreline no males were found (Fig. 5). Therefore, the highest values of individuals' density during all the period of research were defined at a distance of 1 to 6 meters from the shoreline ($r = 0.93$, $p < 0.05$).

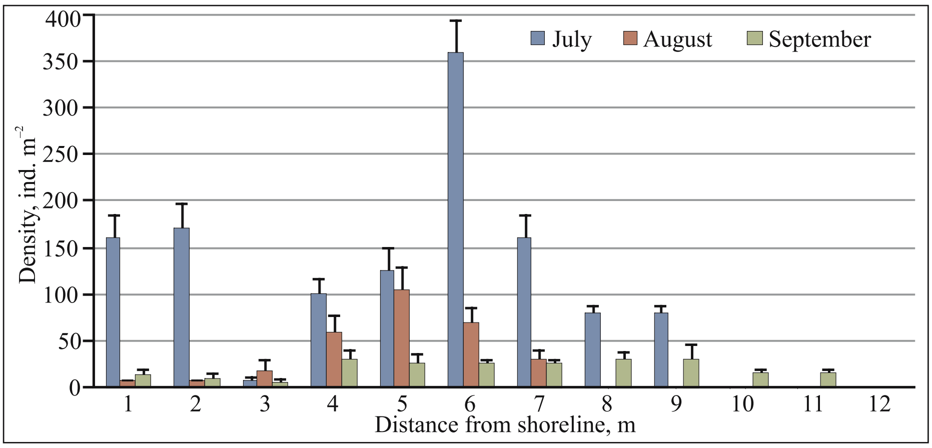

Fig. 3. Spatial (shore–dune) distribution of juvenile individuals

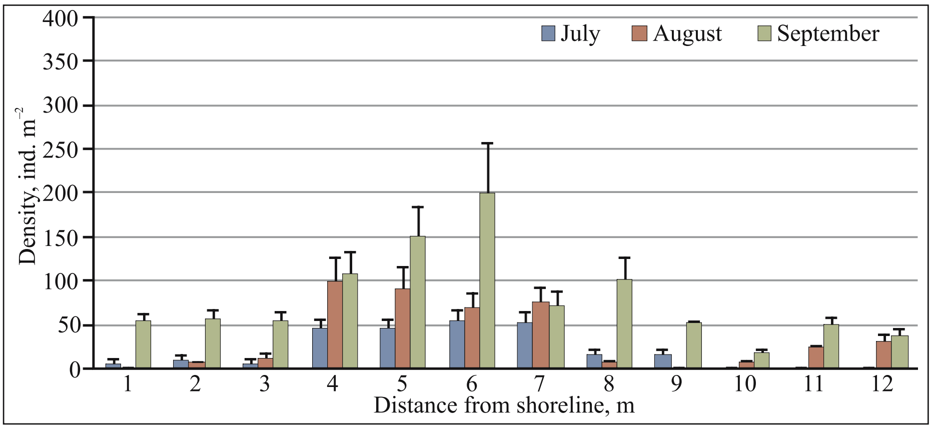

Fig. 4. Spatial (shore–dune) distribution of female individuals

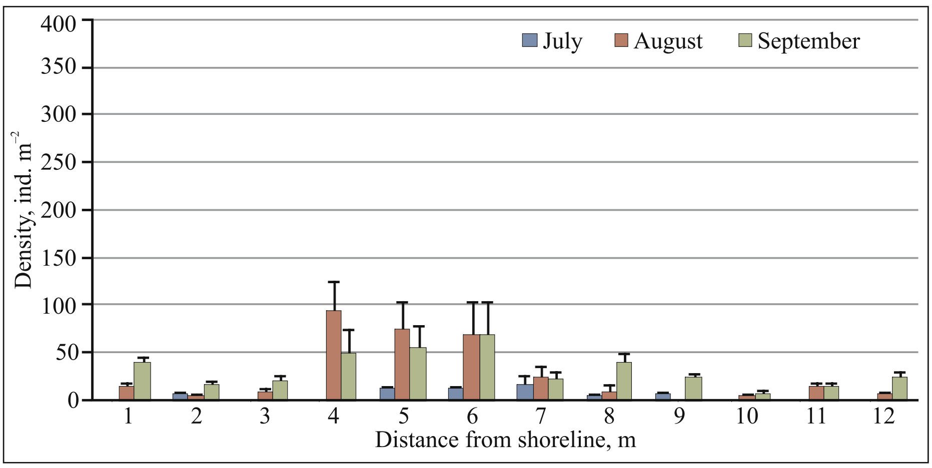

Fig. 5. Spatial (shore–dune) distribution of male individuals

Analysis of population density by time

The highest density of individuals was found in the middle of September (September 16) – 492 ind. m^{-2} and the lowest at the end of August (August 27) – 112 ind. m^{-2}. The highest density of juveniles was found in the first half of July (248 ind. m^{-2}) and the lowest in the second half of September (8 ind. m^{-2}) (Fig. 6). The highest density of adults was defined in the middle of August (224 ind. m^{-2}). The density was lowest in the first half of July (20 ind. m^{-2}). In August, the density of the adults was higher than that of juveniles. Such a ratio of densities was the same up to the end of the study period.

The highest density of females was defined in the middle of September (128 ind. m^{-2}) and the lowest in the first part of July (16 ind. m^{-2}). The highest density of males was defined in the middle of August (120 ind. m^{-2}) and the lowest in the first half of July (4 ind. m^{-2}) (Fig. 7).

Analysis of population biomass by time and space (shore–dune)

The greatest biomass was defined at the end of July (0.28 g m^{-2}) and the least in the beginning of July (only 0.04 g m^{-2}) (Fig. 8). To evaluate the spatial alteration of biomass (shore–dune), analysis at different distances from the shoreline in different months was carried out (Fig. 9). In July, the greatest biomass of individuals was defined in the fourth meter from the shoreline (0.09 g m^{-2}) and in the tenth–twelfth meter it was zero. In August, the greatest biomass of individuals was defined in the fifth meter from the shoreline (0.31 g m^{-2}) and the lowest in the twelfth meter (0.07 g m^{-2}). Meanwhile, in September, the greatest biomass was defined in the fourth meter (0.24 g m^{-2}) and the least in the ninth meter where it reached 0.07 g m^{-2}. The highest values of the biomass were defined within 4–6 meters from the shoreline. Its greatest values coincide with the values of spatial distribution

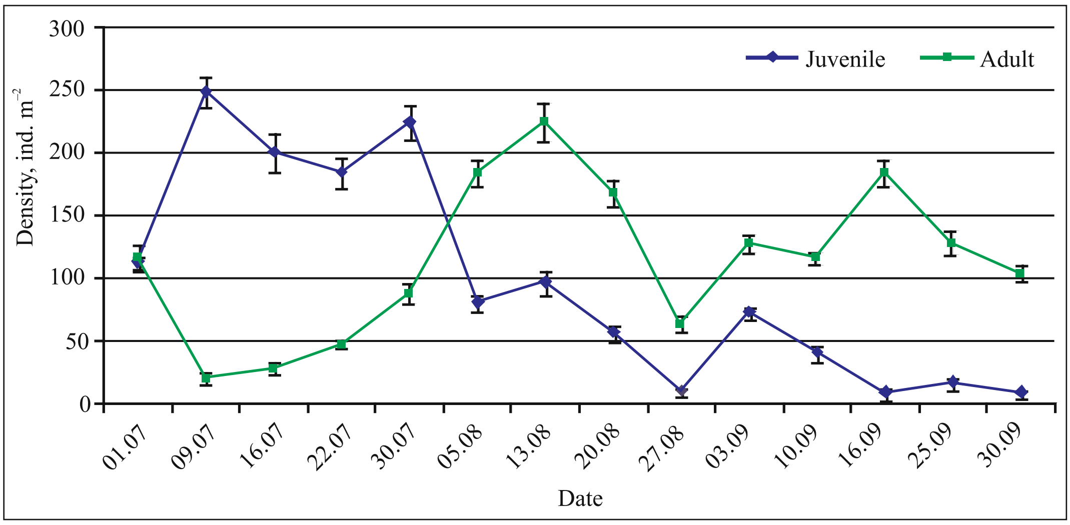

Fig. 6. Density dynamics of juvenile and adult individuals ($\bar{x} \pm s$)

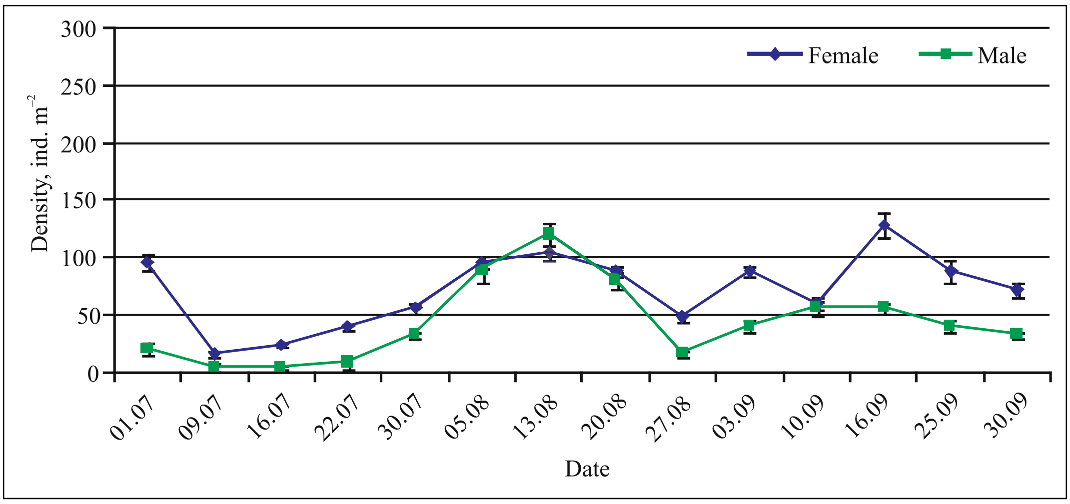

Fig. 7. Density ($\bar{x} \pm s$) dynamics of male and female individuals

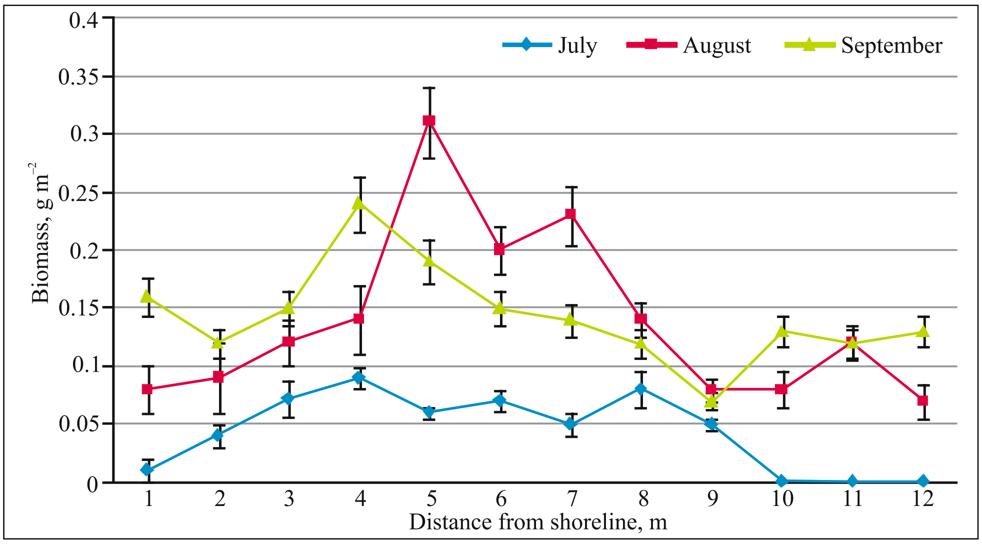

Fig. 8. Spatial (shore–dune) individual biomass ($\bar{x} \pm s$) dynamics

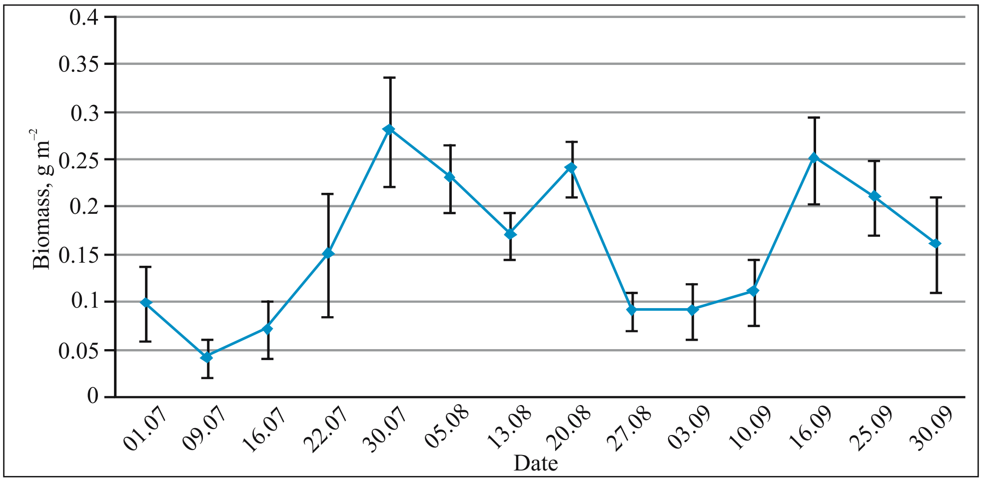

Fig. 9. Population biomass ($\bar{x} \pm s$) dynamics

(shore–dune) of population density (the greatest density of individuals was found also within 4–6 m from the shoreline). However, the greatest values of individual biomass during all the period of research were defined at a distance of 1 to 5 m from the shoreline ($r = 0.86$, $p < 0.05$).

Influence of environmental factors on distribution in time
Two-factor dispersion analysis (ANOVA) confirmed the statistically significant dependence of individuals' density within 1 to 6 m from the shoreline on the intensity of swell ($F = 4.62$, $p < 0.05$) and of individuals' biomass within 1 to 5 m from the shoreline on intensity of swell ($F = 3.94$, $p < 0.05$). A statistically significant correlation was found between individuals' density within 1 to 6 m from the shoreline and wind speed ($F = 3.74$, $p < 0.05$) and between individuals' biomass within 1 to 5 m from the shoreline and wind speed ($F = 3.86$, $p < 0.05$). Multiple class tests showed the density / biomass dependence on the intensity of swell / wind speed: this dependence was significant between places with ahigh and a zero intensity of swell / wind speed. The air and water temperature was not statistically significant for the density ($F = 0.68$, $p > 0.05$ and $F = 0.56$, $p > 0.05$, respectively). The air and water temperature was not statistically significant for the biomass, either ($F = 0.53$, $p > 0.05$ and $F = 0.48$, $p > 0.05$, respectively).

DISCUSSION

Spatial density analysis of the population (shore–dune)
The highest density of adult individuals was established in August–September. Williams (1978) found the highest density of adult *Talitrus saltator* in August, between the third and fifth meters from the shoreline. In our study, the highest density of adult sand hoppers was found within in the fourth–fifth meters from the shoreline. Such distribution of adult sand hoppers could be affected by the content of organic fertilizers on the beach, atmospheric temperature, and soil humidity. Nutrient basis as one of the factors affecting the spatial distribution of sand hoppers was also mentioned meant by Jędrzejczak (2004).

The peak of density of juveniles in July was established in the sixth meter from the shoreline, whereas within 10–12 m no juveniles were found. In August, the maximum juvenile density was in the fifth meter, and within the eighth-twelfth meters no individuals were found. In September, the density of juveniles was highest in the fourth meter, and in the twelfth meter no juveniles were found. Weslawski et al. (2000), who examined sand hoppers population on the beach of Poland, have established that in July and August the density of *Talitrus saltator* juveniles was highest between the second and fourth meters from the shoreline. In this work, the highest density of juveniles in July–August was fixed within 6–5 m from the shoreline. According to this author, in September the juveniles begin to localize closer to the dunes. Such distribution of juveniles is affected by the environmental conditions, such as mechanical influence (human activity on the beach, waves), soil humidity, nutrient basis, seasonal migrations. According to Fuentes (2004), the dependence on habitat humidity for juveniles is higher than for adults capable of living in sand whose humidity is only 2%. Meanwhile, juveniles are more frequently found in sand with the humidity not lower than 85–90%.

The highest density of females, as well as of adults, during the period of all three months was within 4–6 m from the shoreline. Fasulo (2000) states that the distribution of females on the beach, like of individuals of the whole population, during the hottest season is influenced by similar factors, nutrient basis being the most important one.

The highest density of males during the study period was defined in August in the fourth meter from the shoreline, and the highest values of density during all the period of research were established within 4–7 m. Anastacio et al. (2002), Budd (2005), Fuentes (2004), Węslawski et al. (2000) and other authors in their articles do not mention the specific factors that could influence the spatial distribution of population males; they mention only that the distribution of males, as well as of females, or the general distribution of population's individuals on the beach, is affected by environmental conditions.

Analysis of population density by time

The highest density of individuals was found in the middle of September and the lowest density at the end of August. Scapini et al. (1997) reported the highest density of sand hoppers in July–August when sand hoppers show a particularly high reproductive performance. In this work, such a high density of the individuals was induced by warm weather in September (average diurnal air temperature 18.7 °C) and thus a longer period of reproductive performance.

The highest density of juveniles in our study was found in the first half of July when *Talitrus saltator* individuals show the highest reproductive performance. The density of juveniles was lowest in the second part of September. Such a decrease of juvenile density may be explained by their maturing and death because of environmental impacts. Brown and McLachlan (1990) reported the highest density of juveniles also in July. According to these authors, in this period juveniles made approximately 65% of the whole population.

In August, the density of adults was higher than that of juveniles. Such a ratio of densities persisted up to the end of the study period. Marques et al. (1999) indicate that with the end of reproductive performance, the juveniles capable of living in the soil of a 85–90% humidity are frequently washed down to sea by the waves and die there. According to these authors, the juveniles that survive migrate to the dunes, mature and become adults.

The highest density of females was found in the middle of September and the lowest in the first part of July. The highest density of females in September was also fixed by Williams (1978). The highest density of males was defined in the middle of August and the lowest in the first half of July. Charfi-Cheikhrouha et al. (2000), who analyzed the reproductive performance and distribution of *Talitrus saltator* on the beach, established that the density of males was lower than that of females.

The greatest *Talitrus saltator* biomass in our study was found at the end of July and the least at the beginning of July. In the research made by Weslawski et al. (2000), the greatest biomass of sand hoppers also was fixed in the second half of July. Haque et al. (1996) suppose the main factor influencing the biomass of sand hoppers is the quantity of organic substance and its availability on the beach. The density of individuals correlates with the value of population biomass (Budd, 2005). To assess the spatial (shore–dune) change of population biomass, analysis at different distances from the shoreline in the different months was made. In July, the greatest biomass of individuals was defined in the fourth meter from the shoreline, and within the tenth–twelfth meters it was the least one. In August, the greatest biomass of individuals was defined in the fifth meter and the least in the twelfth meter from the shoreline. Meanwhile, in September the greatest biomass was fixed in the fourth and the least one in the ninth meter.

So, the highest values of the biomass were fixed between the 4th–6th meters from the shoreline. They coincide with the highest values (the highest density of individuals during the study period was also within 4–6 m from the shoreline) of population density spatial (shore–dune) distribution. A correlation between sand hoppers' density and biomass is also mentioned by Budd (2005).

While analysing the influence of environmental factors on the density of *Talitrus saltator* population on the beach, correlations between the change of individuals' density and air temperature (°C), water temperature (°C), swell intensity (m), wind speed (m s^{-1}) were checked. However, no statistically significant correlations among separate parameters were found. A relation between atmospheric temperature and the density of individuals was studied by Scapini (1999); however, her studies embraced all seasons of the year, so the temperature amplitude was higher than in the period of our study. Marques et al. (1999) write that juveniles are frequently washed down to sea by the waves and die there, but it is not enough for a significant correlation between population density and swell intensity during our period of research. Fuentes (2004) states that for sand hoppers *Talitrus saltator* anemotaxis is typical. In windy weather they are found at a greater depth, but this does not affect their density. *Talitrus saltator* is influenced by various stress factors: aridity, overwetting, wind, waves, etc. For these reasons they need an orientation apparatus, which helps quickly and in the shortest way to reach a safer place (Fuentes, 2004). Apart from this, the spatial (shore–dune) distribution of sand hoppers on the beach depends not only on environmental conditions, but also on the adaptation mechanism which is inherited or acquired during lifetime (Weslawski et al., 2000). In the life of sand hoppers a huge role belongs to the sun: it is one of the most important orientation factors stimulating phototaxis. Guided by the sun, sand hoppers are capable to migrate to the places that are more favourable for them. This affects their population composition. Oriented adaptation helps to adapt to sudden or directed environmental changes. These animals can also use information from the surrounding environment (Fanini, Scapini, 2005). Fuentes (2004) mentions that sand hoppers of this species can orientate by the "paths" made by other sand hoppers, moon position (at night time), heaven light, beach slope, surrounding objects (for example, dunes), sand humidity and the size of its structural particles. Apart from environmental factors, which influence their ability to orientate, also there are some "internal" factors: gender, age, eye skewness (Fuentes, 2004). Besides, of *Talitrus saltator* sand hoppers circadian cycles are typical because their night time activity begins with sunset and ends after sunrise (El Aoui et al., 2005). Bohli et al. (2005), who examined the dynamics of sand hoppers on the beach, have noticed that their peak of activeness ends at 5–6 a. m. At night, *T. saltator* migrate towards the zone where there is a lot of food. Feeding migrations are different for sand hoppers of different regions: sand hoppers of the Mediterranean Sea at night migrate to the dunes for feeding, and on the shore of the Atlantic Ocean sand hoppers go to feed to the zone of ebb and flow (Nardi et al., 2005).

CONCLUSIONS

1. The highest density of adult *Talitrus saltator* individuals was within 4–6 m, of juveniles 5–6 m, of females 4–6 m and of males 4–7 m. The lowest values of the density were defined beyond 10 m from the shoreline up to the dunes.

2. The density of sand hoppers was highest in the middle of September and lowest in the second half of August. The highest density of adults was fixed in the middle of August and the least in the first half of July. The highest density of juveniles was defined in the first part of July, and the lowest at the end of the period of reproductive performance, i. e. in the second half of September. The highest values of male and female density were fixed in August–September.

3. The greatest population biomass was defined at the end of July when the density of population individuals was high. When juveniles dominated in the population (beginning of July), the least biomass was fixed. The greatest biomass on the beach was established between the 4th and 6th meters from the shoreline.

4. Evaluation of a possible influence of the environmental factors such as air and water temperatures, swell intensity and wind speed on the density of sand hoppers revealed no significant correlation among these parameters.

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SAUSUMOS ŠONIPLAUKŲ (*TALITRUS SALTATOR,* MONTAGU, 1808) PASISKIRSTYMAS BALTIJOS JŪROS LIETUVOS PAPLŪDIMYJE

Santrauka

Talitrus saltator rinktos Baltijos jūros paplūdimyje ties Kuršių nerijos kopgaliu 2005 07 01–2005 09 30, imant mėginius 1 kartą per savaitę. Ištyrus 1044 smiltšoklių individų, nustatyta, kad didžiausias individų tankumas yra 4–6 metre nuo kranto linijos, mažiausias – nuo 10 m iki kopų pradžios. Didžiausias populiacijos tankumas pasiekiamas rugsėjo viduryje (492 ind. m^{-2}), mažiausias – rugpjūčio pabaigoje. Jaunikliai didžiąją dalį populiacijos sudaro pirmoje liepos pusėje, o mažiausią – antroje rugsėjo pusėje. Suaugėlių didžiausias tankumas yra rugpjūčio viduryje, mažiausias – liepos pradžioje. Patinų didžiausias tankumas nustatytas rugpjūčio viduryje, mažiausias – liepos antroje pusėje. Patelių mažiausias tankumas nustatytas liepos pirmoje pusėje, didžiausias – rugsėjo viduryje. Didžiausia populiacijos individų biomasė (0,28 g m^{-2}) tiriamuoju laikotarpiu buvo liepos pabaigoje, mažiausia – liepos pradžioje. Didžiausios biomasės reikšmės fiksuotos 4–6 m nuo kranto linijos. Dvifaktorinė dispersinė analizė (ANOVA) ir Persono tiesinė koreliacija naudota nustatant aplinkos parametrų (oro ir vandens temperatūrų, bangavimo stiprumo, vėjo greičio) ir individų tankumo bei biomasės ryšį.

Raktažodžiai: Baltijos jūros paplūdimys, tankis, *Talitrus saltator*, biomasė