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Thanatocoenoses of mollusc shells in the north-western part of the Black Sea

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abstract

Following death, mollusc shells become elements of thanatocoenoses of bottom and coastal deposits. At the early stages of succession of storm strands, the conservation of mollusc shells in the coastal deposits is high, which allows to obtain a larger number of shells to determine their traits. The probability of finding shells of rare mollusc species in the coastal strands is significantly higher than in bottom grab samples. Therefore, the taxonomic composition of the thanatocoenoses may correspond to the actual composition of mollusc assemblage in the adjacent coastal waters. Determination of the maximum age of molluscs from coastal emissions by sclerochronological methods can be more accurate characteristics of the lifespan of the considered mollusc species. Wind waves are one of the hydrodynamic processes influencing the formation of coastal emissions. The maximum wave activity in the coastal zone of the sea contributes to an increase in the deposition of storm emissions in the coastal zone. Studies of thanatocoenoses of marine molluscs in storm emissions in the north-western part of the Black Sea were carried out at three test sites, differing in the degree of wave load on the coastal zone. Analysis of coastal emissions in different parts of the coastal zone — various distance from the water's edge— allows us to determine the frequency and power of wave activity, as well as to identify the dominant species of macrozoobenthos in each area. The composition and quantitative characteristics of storm emissions created by wave activity of various intensities demonstrates the relationship between benthic biocoenoses of molluscs and thanatocoenoses of the coastal zone. The dominance of bivalve mollusc shells in emissions corresponds to the ruling species of molluscs in benthic biocoenoses. Shells of molluscs of the family Mytilidae were dominant in coastal emissions of the analysed areas. The maximum concentration of aquatic organisms is presented in emissions located near the edge of seawater. A dependence between the total mass of biogenic components in coastal sediments and different distances from the water edge has been revealed for the north-western part of the Black Sea.

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Thanatocoenoses of mollusc shells in the north-western part of the Black Sea. — V. Zolotarev, S. Stadnichenko. — Following death, mollusc shells become elements of thanatocoenoses of bottom and coastal deposits. At the early stages of succession of storm strands, the conservation of mollusc shells in the coastal deposits is high, which allows to obtain a larger number of shells to determine their traits. The probability of finding shells of rare mollusc species in the coastal strands is significantly higher than in bottom grab samples. Therefore, the taxonomic composition of the thanatocoenoses may correspond to the actual composition of mollusc assemblage in the adjacent coastal waters. Determination of the maximum age of molluscs from coastal emissions by sclerochronological methods can be more accurate characteristics of the lifespan of the considered mollusc species. Wind waves are one of the hydrodynamic processes influencing the formation of coastal emissions. The maximum wave activity in the coastal zone of the sea contributes to an increase in the deposition of storm emissions in the coastal zone. Studies of thanatocoenoses of marine molluscs in storm emissions in the north-western part of the Black Sea were carried out at three test sites, differing in the degree of wave load on the coastal zone. Analysis of coastal emissions in different parts of the coastal zone — various distance from the water's edge—allows us to determine the frequency and power of wave activity, as well as to identify the dominant species of macrozoobenthos in each area. The composition and quantitative characteristics of storm emissions created by wave activity of various intensities demonstrates the relationship between benthic biocoenoses of molluscs and thanatocoenoses of the coastal zone. The dominance of bivalve mollusc shells in emissions corresponds to the ruling species of molluscs in benthic biocoenoses. Shells of molluscs of the family Mytilidae were dominant in coastal emissions of the analysed areas. The maximum concentration of aquatic organisms is presented in emissions located near the edge of seawater. A dependence between the total mass of biogenic components in coastal sediments and different distances from the water edge has been revealed for the north-western part of the Black Sea.

Key words: Black Sea, thanatocoenosis, bivalve mollusc shells, storm strands

Introduction

Bivalves and gastropods are widespread in many marine bottom biotic communities. After the molluscs died, their shells become elements of thanatocoenosis — subfossil groups in modern bottom and coastal deposits. In many regions, such shells are their main component (López *et al.* 2008; Kosian *et al.* 2012; Ponomareva & Krasnov, 2012; Shadrin 2013).

According to the origin of remains of the dead animals, two types of marine thanatocoenoses are distinguished — autochthonous and allochthonous (Kidwell *et al.* 1986). The first are formed by remains of organisms in their habitat, whereas allochthonous thanatocoenoses are formed because of the animal remains' movement. Such type of thanatocoenosis is common in coastal bottom and coastal deposits. Autochthonous thanatocoenoses are the result of past ecological conditions in their area and therefore they can be a source of information about communities and ecological factors dynamics that brought the biocenoses to the present state (Kidwell 2007; Olzewski 2012).

The composition of the redeposited complex of mollusc shells and particular qualities of their spadger spacing in bottom and coastal deposits are determined by two main factors: structure of the initial mollusc community and postmortem sorting and destruction of their remains. A clear example of sweeping changes in the composition of coastal thanatocoenosis caused by transformations of benthos zoocoenosis is the appearance of a large number of shells in coastal deposits of many regions

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of the Black Sea. *Mya arenaria*, *Anadara kagoshimensis*, and *Rapana venosa* are introduced molluscs that became abundant in benthic communities of this basin (Zolotarev 1996; Gomoiu & Skolka 2005; Shalovenkov 2000, 2017).

Shells and coastal washouts of their fragments are replenished and sorted randomly throughout the year, but more intensively by storm waves, in which benthic organisms and their remains are transported to the coast highest level (Lópes et al 2008). The rate of subsequent destruction of shells due to various destructive factors varies depending on morphological features and thickness of shells, on the structure of their main layers, on the amount of organic matter in them, on movement features and on the burial of shellfish remains (Taylor & Layman 1972; Zuschin & Stanton 2001; Zuschin *et al.* 2003; Basso & Corselli 2007). In a point of fact, molluscs of the Black Sea have maximum organic matter in layers with a nacreous structure (*Mytilus galloprovincialis)* and far less in layers with cross-slaty structure (*Chamelea gallina*) and homogenous structure (*Mya arenaria*). Size is usually less important to shell strength than shell thickness (Zuschin *et al.* 2003).

Evaluations of conformance between subfossil and fossil mollusc remains and the original biocoenosis are numerous in palaeoecological studies (Lockwood & Chastant 2006; Basso & Corselli 2007; Kidwell 2007; Kidwell & Bosence 1991; Olzewski 2012). Shells of thanatocoenoses are much less frequently used in studies of modern biological processes. At the early stages of succession of modern coastal deposits, the preservation of shellfish remains is usually high; therefore, during their examination, it is possible to obtain a significantly larger number of shells for subsequent determination of their various structural and functional characteristics than when collecting shellfish by standard hydrobiological methods. Determination of the maximum age of molluscs from coastal drains by sclerochronological methods can be more precise life endurance capabilities of the species under consideration (Zolotarev 1989). It is possible to calculate individual equations of molluscs growth by annual layers of subfossil molluscs shells to assess the growth and mortality characteristics of long-living molluscs, individuals with different phenotypic traits or with rare shell physiography (Zolotarev 2014), and to identify and analyse long-term growing rhythms. The characteristics of subfossil molluscs are also promising in the analysis of energy flow between sea and land, environmental monitoring of the coastal zone (Agarkova-Lyah 2005), seawaters bioindication (Ponomareva & Krasnov 2012), identification of anthropogenic environmental changes (Kidwell 2007), assessing storms strength in relation to entire valves and their debris (Ponomareva & Krasnov 2012). Another area of biological research on mollusc shells in benthic biocoenosis, which has been actively developing in recent years, is molluscs as ecosystem engineers (Gutiérrez *et al.* 2003; Prado & Castilla 2006; Borthagaray & Garranza 2007).

Shells of living and defunct molluscs, especially their accumulations, can be a substrate for the attachment of various aquatic organisms and accommodation for smaller organisms. As a result, the biodiversity and productivity of biocoenosis increases. However, such studies in the Azov and Black Sea basin based on the composition and chorological characteristics of mollusc thanatocoenosis are not numerous.

The aim of the study is to reveal the qualitative composition and equivalence of storm drains created by wave action of varying intensity in the coastal zones of the north-western part of the Black Sea, as well as the relation between the characteristics of benthic mollusc biocenoses and thanatocoenosis of the coastal zone.

Material and Methods

To identify the composition and quantitative accounting of aquatic organisms of storm drains (accumulations of animal and plant organisms, as well as their beached remains) samples were collected in the north-western part of the Black Sea on 18–20 May 2015 after the previous autumn-winter period with active wave activity. When choosing a sampling season, it was taken into account that in Odessa Bay the maximum number of shells of mollusc species were present in emissions of the most intense winter storms (Bezuglova 2012). On the Baltic Sea coast (Kaliningrad region), the largest number of valves was found during spring and summer surveys (Ponomareva & Krasnov 2012).

Studies of thanatocoenoses of marine molluscs in storm drains of the north-western Black Sea were carried out at three polygons differing by the degree of seaway load on the coastal zone: in the coastal zone of Bugovo village near Chernomorsk (46°16.05'N; 30°38.56'E) (Fig. 1, 2) on horizons with distances from water edge of 1.5, 2.5, 5.0, and 15–17 m; at promontory Bolshoy Fontan of Odessa Bay (46°22.48'N; 30°45.12'E) on the horizons 2 and 15 m; on the tip of the Kinburn Peninsula (46°28.00'N; 31°39.76'E) (Fig. 3) at a distance of 1.7 and 10 m from the water edge. Moreover, in the Bugovo area, subfossil shells of molluscs were collected from the surface of bottom deposits at a distance from the coast of 2 to 500 m. According to the relevant recommendations (Zuschin *et al.* 2003), mollusc shells were considered as intact specimens with more than 90 % of their initial form preserved.

A plastic frame 26 × 40 cm in size fixed the sampling area. Collected coastal deposits layer thickness varied from 1 to 10 cm. Due to the high compositional disorder of drains, samples were taken in 3 recurrence at a distance of 5 m from each other at the same distance from the water edge. For each sample, the total mass of each detected species of molluscs, algae in general, fragments of shells of molluscs more than 3 mm in size, the total number of remains of aquatic organisms, as well as the mass of stones, sand and debris, the total mass of all components of coastal deposits sample was determined. For comparison, all mass values obtained for each sample come of a single volume — 0.005 m^3.

Average abundance (ind. m^2) was determined for each species for 5 studied deep horizons (0.5, 1.6, 2.2, 4.9, and 7 m), according to subfossil shells of molluscs collected in the upper layer of bottom deposits at the Bugovo range.

The same method was applied in title of thanatocoenosis that is used to distinguish modern biotopes — according to the dominant species (communities) in environmental representative condition (Olenin & Ducrotoy 2006).

Results and Discussion

Wind-driven waves are one of the components of hydrodynamic processes that affect the formation of coastal storm strands. It has the greatest impact on the coastal zone at wave heights of more than 1.0 m. In the north-western part of the Black Sea, in 2014, preceding these studies of mollusc thanatocoenoses, an increase in wind activity was observed with an annual frequency of storm waves repetition of up to 15.8 %, the maximum over the past 15 years (Adobovskii & Krasnodembskii 2015). Analysis of storm drains in different coastal zone parts of this region is indicative of frequency and power of wave activity, revealing the dominant species of macrozoobenthos in each area.

Among the studied areas, Bugovo range is distinguished by a fair wave height not exceeding 1.8 m, but the maximum area of coverage of the coastal zone by drains of about 150 m in length at a distance from the water edge up to 17–20 m, and in its narrowest corner part up to 80 m. Its offshore strip is characterised by two main biotopes that were exposed to wave effect and gave rise to mollusc shells in coastal drains: sandy bottom deposits with bivalve molluscs of *Spisula, Anadara, Abra, Mya,* and *Chamelea*, as well as a lithoidal kettle back at a depth of 4.5–5.6 m, which is a substrate for the attachment of bivalve molluscs of *Mytilus* and *Mytilaster*.

Therefore, storm drains from this range contain mollusc shells, both burrowing and secured, but mollusc shells of the family Mytilidae (*Mytilus galloprovincialis* and *Mytilaster lineatus*) with a mass of 497.3 g to 1734.5 g in 0.005 m^3 prevailed at all distances from the water edge, significantly larger than the total mass of the remaining molluscs found. However, other components of coastal drains (fragments of mollusc shells, sand, stones) and their amount differ at different distances (horizons) from the water edge.

Therefore, in Bugovo region, two thanatocoenoses of Mytilidae are distinguished: in shell deposits with stones (horizons 1.5 m and 5 m) and in sandy-rocky soil (horizons 2.5 m and 15–17 m).

Fig. 1. Stranded shells of mollusc and plant organisms after the storms, polygon of Bugovo, May 2015.

Рис. 1. Штормові викиди мушель молюсків і рослинних організмів і їх залишків, полігон Бугово, травень 2015 р.

Fig. 2. The relief of the coastal zone, Bugovo, May 2015.

Рис. 2. Рельєф берегової зони, полігон Бугово, травень 2015 р.

Fig.3. Stranded shells of mollusc and plant organisms after the storms, Kinburn Spit, May 2015.

Рис. 3. Штормові викиди мушель молюсків і рослинних організмів і їх залишків, Кінбурнська коса, травень 2015 р.

Herewith, the total mass of shells, their fragments and algae on all horizons changes insignificantly from 1820 g to 2479 g per 0.005 m^3 (Table 1). That is grounds for assume comparable wave action at different previous autumn-winter period timespan.

The species composition of allochthonous mollusc thanatocoenoses in bottom deposits of this region also corresponds to two initial substrates — sandy-silty deposits and hard rocky substrates. As it approaches the coast, the number of *Mytilus* shells increases from 3100 specimens per m^2 at a distance of 500 m from the coast (deep 7.0 m) to 16100 specimens per m^2 at a distance of 2 m from the coast (deep 0.5 m). This kind of predominance of subfossil shells near the water edge is also typical for other bivalve molluscs such as *Chamelea, Cerastoderma, Anadara,* and *Mya*. The only exception is *Mytilaster*. The number of its shells is maximal at a depth of 7 m — 12033 specimens per m^2, which is much higher than the total number of all other encountered molluscs, but it decreases to 273 specimens per m^2 at a depth of 0.5 m. Such massive reduction of these mollusc remains in the coastal zone may be the result of their weak resistance to mechanical destruction during storm movements of bottom deposits.

Aquatic biotopes at promontory Bolshoy Fontan are represented by alternating solid (rocks, stones) and soft (sand, silt) soils, therefore, drains are represented by a mixture of shells (and their fragments) belonging to the families *Mytilidae, Cardiidae, Veneridae, Arcidae, Myidae*, etc. (Table 1). However, the shells of molluscs of the family *Mytilidae* were predominant, as in the Bugovo polygon. But in coastal deposits at horizons with a distance of 2 m and 15 m from the water edge, the bulk of subfossil remains of molluscs were small fragments of shells, the mass of which was much larger here than in other studied areas reaching 2.88 kg and 2.34 kg in soil samples with a volume of 0.005 m^3. Such ample quantity of shell debris in coastal drains may be the result of a significant amount of coastal rocks and stones, which contributed to the destruction of mollusc shells with increased storm activity with a maximum wave height of up to 3 m.

Table 1. **Composition and mass in strandings of various regions of the north-western Black Sea, 2015 (in grams per volume · 0.005 m^3)**

Таблиця 1. **Склад штормових викидів в різних районах північно-західної частини Чорного моря в 2015 р. (у грамах в об'ємі · 0,005 м^3**

Region	Polygon							
	Bygovo				Kinburn Spit		Bolshoy Fontan	
distance from the wate edge, m	**1.5**	**2.5**	**5**	**15–17**	**1.7**	**10**	**2**	**15**
Mytilidae	1506.7±282.7	497.3±83.2	1658±199.1	1734.5	272.8	482	767±127.0	463.3±161
Veneridae	33.85±1.77	11.87±3.58	22.71±3.58	13.98	111.67	1.173	205.5	161.2±74.9
Cardiidae	21.741±1.95	13.15±2.09	37.09±1.42	70.38	58.6	7.236	199±113.7	119.3±61.7
Mya	27±4.7	12.34±0.48	50.17±2.02	42.01	218.24	9.222	2.91±2.5	4.79±0.23
Anadara	2.74±0.42	3.29±2.13	14.42±2.38	28.49	133.25	46.096	–	–
Gastropoda	–	11.17±1.54	20.87±2.14	43.23	2.19	0.561	3.36±1.6	4.9±2.3
Loripes	–	–	–	–	0.7	–	0.3±0.2	–
Abra	–	–	–	–	0.32	–	2.03±1.2	–
Ostrea	6.53±0.67	–	8.16±0.79	13.61	3.56	0.584	10.6±0.7	10.6±6.5
Alga	161.3±118.9	1271±292.6	–	38.87	51.93	0.38	17.9	101.7
Shell parts ≥3 mm	719.59±211	–	162±69	–	–	–	1671.2±45	1469.2±651
Sum	**2479.45**	**1820.12**	**1973.42**	**1985.07**	**853.26**	**547.25**	**2879.40**	**2335.0**
Stones	622.3±259.7	883.4±141.2	418.7±87.6	110.46	–	–	15.8	33.3±13.4
Sand	–	740±198.5	–	1999.2	2098.1	1274	–	–
Garbage	50.1	–	28.23±22.9	–	–	18.14	11.9	3.75±2.5
Total	**3151.85**	**3443.52**	**2420.35**	**4094.73**	**2951.36**	**1839.75**	**2907.10**	**2372.04**

An increase in the number of subfossil mollusc shells in bottom deposits at Bugovo range with a decrease in the habitat depth from 7 m to 0.5 m may also be associated with the differences in the storm waves frequency (Table 2). The biotope at a depth of 7 m is exposed to intense, but rarer storm waves, while at shallower depths, bottom biocoenoses find themselves in the zone of influence of weaker, but constant waves, which move the biogenic components of thanatocoenoses to the coastal zone.

Table 2. **The average number (ind × m^{-2}) of bivalve mollusc shells in bottom sediments at the Bugovo polygon, 2015.**

Таблиця 2. **Середня чисельність (екз × м$^{-2}$) мушель двостулкових молюсків в донних відкладах на полігоні Бугово в 2015 р.**

Depth, m	*Mytilus*	*Chamelea*	*Cerastoderma*	*Mytilaster*	*Anadara*	*Mya*
0.5	16100±5717	367±115	1733±723	273±57	300±100	300±100
1.6	9733±5615	467±289	933±451	267±153	67±115	200±174
2.2	1233±551	100±100	300±100	400±361	–	–
4.9	5667±1935	200±100	300±100	633±611	–	233±321
7.0	3100±1136	33±58	233±58	12033±11047	33±37	67±58

Such pattern of coastal storm strands formation generally corresponds to the mollusc thanatocoenoses in the three considered areas. In each of them, coastal drains far from the water edge are formed because of the most intense storms, which probability of occurrence is much less likely than weaker, but more frequent storm waves in the coastal zone.

For Kinburn Spit water zone, with a maximum wave height not exceeding 1.25 m, the dominant biotope is soft soils, therefore, at the 1.7 m horizon, closest to the water edge, along with the *Mytilidae* valves, remains of burrowing molluscs of the family *Veneridae*, genus *Anadara* and *Mya*, but mostly in sandy drains. Only at a greater distance from the coast, molluscs of the family *Mytilidae* remained widespread (Table 1).

Algae and their remains are a secondary biogenic component of storm drains in the studied areas. Their maximum number (1271 g in 0.005 m^3 of sample) was found only in the coastal zone of Bugovo polygon at a distance of 2.5 m from the water edge. Algae share, bulk of which are representatives of genera *Ceramium and Ectocarpus*, reaches 70 % of the total mass of algae and mollusc shells in drains. Algae of the genera *Ulva (Enteromorpha), Cladophora, Desmarastia,* and *Polysiphonia* were found in smaller quantities. Algae drains percent located at a distance of 1.5 m from the water edge was 9 %, and at a distance of 15 m — less than 2 %. Such algae distribution at various distances from water edge is quite understandable, since when the algae dry up, they lose weight, their dried vestige is carried away by the wind from coastal zone over long distances. Therefore, it is problematic to judge their real initial content in storm drains at a distance from water edge.

In the coastal zone of promontory Bolshoi Fontan, algae drains proportion is insignificant and amounts to 1.5 % at a distance of 2 m from the water edge and 11.7 % at a distance of 15 m. The bulk of algae belonged to sippe *Chlorophyta* (*Enteromorpha*), *Phaeophyta* (*Ectocarpus siliculosus*), and *Rhodophyta* (*Polysiphonia denudate, Ceramium rubrum*). It is possible that the algae amount at a distance of 15 m is total, accumulated over several storms, since after drying, algae drains part by wind influence can change its location on the shore.

Minimum amount of algae was detected in the storm drains of Kiburn Spit coastal zone. Here their share is 6.1 % at a distance of 1.7 m from the shoreline and less than 0.1 % at a distance of 10 m. Algae residues taxonomic composition of Kiburn Spit is similar to that in the emissions of Bolshoi Fontan.

It follows from the data obtained on the structure of mollusc thanatocoenoses in three regions of the north-western part of the Black Sea that the complex composition of redeposited mollusc shells and their distribution in bottom and coastal deposits are determined by two main factors: initial biotope nature, precisely, biocenosis structure and substrata type, storms frequency and intensity. There are three stages in such drains formation on coastal beaches (López *et al.* 2008). Directly during a storm, organisms and their remains are transferred to the highest level of the coast, which storm waves reach. At the second stage, after the storm, numerous organisms displaced from the depths by less active waves are transferred to the appeared beach. At the third stage, sand-shell bars are formed in the surf zone as a result of beach drains erosion that appeared after previous storms, which can move with various wave activity.

Therefore, a priori as can be expected in the supralittoral zone, closer to the water edge, storm strands total biomass will be higher than at a distance from the coast. Indeed, such a balance between the total mass of animal and plant remains thrown up to 2 m from the shoreline and up to 10–15 m from it was noted in all analysed areas. In general, the total mass ratio of biogenic components of coastal storm strands at horizons up to 2 m [B_2, g × $(0.005 \times m^3)^{-1}$] and more than 10 m from the water edge [B_{10}, g × $(0.005 \times m^3)^{-1}$] is described, although on a limited amount of initial data, the equation of the linear regression is as follows:

$B_{10} = 385 + 0.54\,B_2$, (r = 0.96; F = 53.67; p = 0.0018).

The ratio of shell biomass of molluscs of the family *Mytilidae (Mytilus galloprovincialis* and *Mytilaster lineatus*), which are the main components of thanatocoenoses of coastal emissions, at the same distances from the water edge (BM_2 and BM_{10}) are also described by a regression equation with a high correlation index: $BM_{10} = 352 + 0.49\,BM_2$, (r = 0.91; F = 25.48; p = 0.0039).

In the range of Bolshoi Fontan Cape, low frequency storm waves in July–August contributed to the intensive development of the seasonal thermocline with a temperature gradient of up to 5° C between depths of 4 and 10 m, as well as with a reduced oxygen content in lower horizon waters. Consequently, the annual mortality rate of mussels *Mytilus galloprovincialis* grown in vivarium was almost two times higher in the lower horizon than in the upper one (Zolotarev & Adobovskii 2015). In Odessa Bay, as a result of benthal hypoxia, which in September 1990 lasted for more than two weeks, the biomass of mussel settlements at a depth of 6 to 15 m decreased by two times (Shurova 2000), which led to a significant increase in the number of dead mollusc shells in bottom deposits. Zones of stable water hypoxia and associated suffocation of the benthic fauna are widespread in the north-western part of the Black Sea causing significant decrease in population density and biomass of mussels (Shurova 2000; Northwestern part… 2006). Obviously, this excess mortality associated with oxygen debt in coastal waters is also characteristic for other molluscs. Therefore, it can be assumed that in the north-western part of the Black Sea, hypoxia of bottom waters along with high storm activity is another significant factor of thanatocoenoses formation. Under the conditions of low summer storm activity, mortal remains of molluscs that died during suffocation replenish autochthonous and allochthonous thanatocoenoses in many coastal zones of this region. Ulteriorly, with autumn–winter storm waves reinforcement, these shells and their fragments become components of coastal storm strands at different distances from the water edge.

Conclusions

Components and quantities of storm strands in the studied areas of the north-western part of the Black Sea depend on biotope nature, particularly on biocoenosis type of soil and structure. Maximum wave activity in the nearshore coastal zone contributes to an increase in deposits of storm strands. Prevailing mollusc species in benthic biocoenoses also appear to be the dominant species in coastal drains. The highest concentration of aquatic organisms was found in storm strands located near the seashore.

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