Morphodynamic features of the development of frontal shores coastal barriers of non-tidal seas

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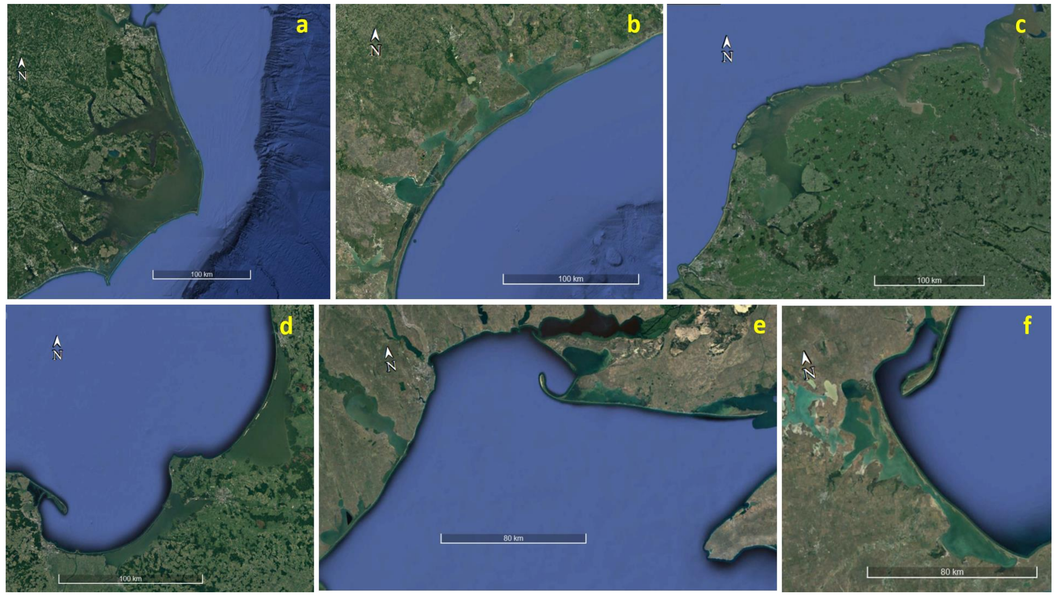
Introduction. Coastal barriers are accumulative forms located along the indigenous shores, which completely or partially separate bays, lagoons, and estuaries from the open waters of the seas and oceans. Functionally, these formations protect the shores of shallow water areas from the effects of the open water waves. Coastal barriers are spread out along 13% of the entire length of the World Ocean coast (*Зенкович, 1962; Леонтьев, Никифоров, 1965; Encyclopedia, 2010; Stutz, Pilkey 2011*). Despite its wide distribution, the degree of study of barriers differs significantly between ocean and sea coasts. Barriers of oceanic shores, which develop in conditions of tidal fluctuations, are the most thoroughly studied and described (*Davis, Fitzgerald, 2004; Bird, 2008; Kusky, 2008; Haslett, 2009; Moore, 2018*).

Formulation of the problem. According to publications in recent years (*Jarmalavičius, et al., 2012; Бобыкина, 2015; Pupienis et al., 2017; Бабаков, 2018; Zaromskis, 2018; Žilinskas, et al., 2007; 2018; 2020; Стонт, 2019*), the Curonian – Baltic barrier is developing under conditions of sea level rising and storm activity intensification. However, within the frontal part of the barrier, the morphodynamic situation is ambiguous. In the southern part of the Curonian Spit, there is an active erosion and retreat. The coastline within the northern part of the spit is in a state of dynamic equilibrium, with the dominance of accumulation and progradation.

There are three coastal barriers within the northwestern part of the Black Sea. The morphodynamic features of the barrier, located between the mouth area of the Dniester and the Danube, are the most thoroughly studied (*Шуйский, 1968; 1975; 1989; 1991*). The Kinburnska-Pokrovska-Dovgiy and Tendra-Dzharylgach barriers, located between the Dnieper estuary area and the Bakalska spit, have been studied to a much lesser extent (*Зенкович, 1960; Шуйский, 1999; 2005*).

Materials and research methods. The study of the morphodynamic features of the Kinburnska-Pokrovska-Dovgiy and the Tendra-Dzharylgach coastal barriers were carried out during complex research expeditions and laboratory studies in the period from 2003 to 2021. We used the method of geomorphological profiling associated with the benchmark network to determine the quantitative characteristics of the dynamics of coastal processes. The method of coastline fixing using a GPS receiver was also used. This method made it possible to determine the development trends of the coastline of the studied barriers in laboratory conditions. To determine the morphodynamic and evolutionary features of the barriers, we also used aerial photography materials, which were processed using the Pix4D program

Research methodology: a - stationary benchmark; b - geomorphological survey; c - GPS receiver; d - photo of the coastal barrier from an unmanned aerial vehicle; e - photo of the barrier from the quadcopter.



Coastal barriers of the World Ocean: a - Cape Hatteras area, Atlantic Ocean; b - the coast of the Gulf of Mexico; c - the coast of the North Sea (all within the tidal shores); d - Curonian - Baltic, southwestern part of the Baltic Sea; e - Tendra - Dzharylgach, northwestern part of the Black Sea; f - Arabatskaya Strelka, western part of the Sea of Azov (all within the non-tidal seas)

Research results. According to the materials of earlier studies, a steady retreat of the coastline occurs at a rate of 0.2 to 2.8 m/year along the front of the Kinburnska-Pokrovska-Dovgiy barrier (*Шуйский, 1999*). Our studies indicate seasonal and interannual variability in the morphodynamic trend of the coastline caused by climate changes. In the cold period of the year, widespread erosion is manifested, with a retreat of the coastline up to 2.0 - 2.5 m. In the warm period, accumulation dominates along the barrier contour, with quantitative characteristics from 1.0 to 3.5 m.

Studies of the coastline dynamics of the Tendra-Dzharylgach barrier were episodic. In the specialized literature (*Зенкович, 1960; Правоторов, 1968; Шуйский, 2005*), an idea about the stable tendency of the coastline of the barrier towards widespread erosion and retreat has been formed. Our studies indicate the ambiguous nature of the dynamics of the studied barrier, which we associate with climatic changes and the implementation of coastal protection measures within the bedrock ledge. Within the barrier, there is a seasonal and long-term variability of the coastline dynamics, while it is significantly complicated by the periodic manifestation of the washouts inlets (*Davydov, Karaliūnas, 2020*).

Along the front of the Tendra-Dzharylgach barrier, the areas with anomalously high erosion rates appear with a certain periodicity. As a result, the straits are formed within the accumulative forms, in the area of which the coastline is depressed towards the bays. The dynamic situation, in the area of washouts inlets, depends on the hydrological conditions of the surrounding water areas (*Давыдов, Черняков, 2020*). In areas of periodic occurrence of inlets, the dynamic trends of the coastline have certain patterns. At the stage of formation and identification of washouts inlets, anomalous erosion rates appear within the coastline of the spit, ranging from 10 to 20 m/year. At the stage of the inlet closing the accumulation processes are dominated with speeds of 20 to 50 m/year. On the sections of coastal barriers located outside the inlets area, the coastline has seasonal and long-term dynamics, which allows us to assert of a dynamic equilibrium state.

Features of the dynamic tendencies of the frontal coastline of the Tendra Spit: a - the state of the spit before the formation of the washout inlet; b - condition of the spit in the area of the inlet; c and d - the state of the spit outside the inlet formation zone.

Conclusions. The conducted studies of the morphodynamic features of the non-tidal sea coastal barriers, allow to come to the following conclusions:

- coastal barriers located within the northwestern part of the Black Sea are characterized by the dynamic equilibrium state, without occurrence of stable retreat or progradation of the coastline;
- the most dynamically active areas of coastal barriers are located within the areas of washout inlets, however, the evolutionary orientation allows the coastline to return to a dynamic equilibrium state;
- the dynamic equilibrium state, within the studied coastal barriers, cannot be accepted for all similar formations of coastal barriers of non-tidal seas.