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Spatial landscape differentiation of the coastal geostructure of the Shkota Island, Sea of Japan

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Abstract

Existing plans for the development of the continental coast and the islands of the Peter the Great Bay suggest establishing of large economic clusters. The most important condition for achieving sustainable development of the emerging natural-economic system is to implement spatial planning of coastal zones. The work is based on the information about the natural complexes of the territory and water area, obtained through landscape approach. The territory of the Shkota Island and its submarine slopes were used as a key area for the study of the features of the spatial organization of landscapes of coastal geostructures. We used a complex of physiographic, geoecological, cartographic and statistical research methods. For terrestrial landscapes, 49 observation points are described and 4 profiles are laid; for underwater landscapes 64 observation points are described and 18 profiles are laid. As a result, a unified structural-genetic classification of land and underwater landscapes is established, the landscapes are mapped, and zones of interaction between aerial and aquatic natural complexes are identified. The results obtained are the basis for identifying priority types of coastal-marine environmental management, functional zoning and spatial planning.

Key words: *coast types, coastal geostructure, mapping, terrestrial landscapes, underwater landscapes*

INTRODUCTION

The contact zone between land and ocean is characterized by the highest degree of landscape and biological diversity, where most of the population and industrial centers of the Earth are concentrated. In the coastal area, marine and coastal landscapes provide a wide range of opportunities for economic activities related to the use of biological, mineral, and energy resources. The recreational potential and the values of natural and cultural heritage are concentrated along the coast [MANEA *et al.* 2019; TEOH *et al.* 2019]. At the same time, global climate change is primarily manifested in the transformation of natural and economic complexes of coastal zones and coastal waters. Economic activity in these areas intersects with natural processes that form coastal zones and largely determine the nature of the resource base [ELLIOTT *et al.* 2019; RAMESH *et al.* 2015]. Consequently, coastal zones are at the forefront of sustainability problems due to ever-increasing pressure from economic development and the associated population growth. At the same time, these areas are the most affected by climate change, including sea level rising [BORJA *et al.* 2016; VISBECK 2018]. It results in the difficulties of coastal management at different scales with an ever-changing interaction between different areas of legislative control, institutional hierarchies, social factors and values [ROCHETTE *et al.* 2015], as well as the need to consider all mapping data to implement the spatial planning policy [BIEDA 2017].

Currently, the policy of polarization development is being implemented in the Far East of Russia. As of now, 18 territories of advanced socio-economic development are functioning in the region (4 of them in Primorsky Kray), the Free Port of Vladivostok is open, 800 investment projects are being implemented [KRDV 2018], and a Special

Administrative Region has been established for Russky Island. In May 2017, the concept of Russkiy Island development before 2027 was adopted [Pravitel'stvo Rossiyskoy Federatsii 2017]. Its goal is to create international economic clusters on the islands of Peter the Great Bay, which will have a multiplicative effect on the socio-economic development of the region.

Comprehensive physiographic, geo-ecological and socio-economic studies of coastal-marine areas reflect the objective existence of terrestrial-aquatic natural systems or coastal geostructures [BAKLANOV *et al.* 2018; IVANOV, SHAPOVALOVA 1997; PETROV 1971]. The natural integrity of these formations follows the flow of matter and energy in two-way direction – from land to sea and from sea to land [IVANOV, SHAPOVALOVA 1997].

Coastal geostructures perform binding functions in the development of coastal-marine environmental management. Their resource properties have a decisive influence on the nature, ecological and economic efficiency of economic activities in the coastal zone [BAKLANOV *et al.* 2018].

Understanding the exceptional importance of the landscape in the conservation of natural and cultural heritage as the basis for sustainable development led to the adoption of such documents as the European Landscape Convention, the UNESCO World Heritage Convention, as well as many national programs and plans. In Russia, a national strategy determining the achievement of a balanced sustainable development of the economy and the social sphere with the preservation and improvement of the environmental situation as a priority activity was adopted in 1994.

In order to achieve priorities for sustainable development in coastal areas, landscape and marine spatial planning (MSP) are being actively developed worldwide [ANTIPOV, SEMENOV 2006; EHLER, DOUVERE 2009]. Both approaches are based on the methods of strategic and long-term spatial planning, focusing on resolving potential conflicts between economic use and the preservation of natural complexes of the coastal zone, as well as between environmental users competing for space [KIDD, ELLIS 2012]. The planning process identifies current and potential threats, as well as opportunities to minimize these threats and the development of economic activity.

Spatial planning in coastal zones is aimed at solving problems of conservation of resources and ecosystem services, establishing the impact of existing and planned forms of environmental management on natural systems, as well as the reverse impact of systems on economic activity. One of the key results of spatial planning is the definition of environmental quality criteria, which serve as benchmarks for territorial development and construction, as well as the provision of environmental impact assessment of projects and the development of measures to regulate environmental impacts [FOLEY *et al.* 2010].

The foundation for effective planning decisions for the economic development of a territory is integrated data on the natural spatial organization. It can be obtained by conducting comprehensive studies using a landscape approach.

The purpose of the work is to identify the spatial organization of aerial and aquatic natural complexes of the Shkota Island based on the results of comprehensive field studies, including mapping of terrestrial and underwater landscapes, and to determine geomorphological types of its coasts. As a working hypothesis, an assumption was made about the interconnected functioning of terrestrial and underwater landscapes. Landscape-forming processes determine the two-way impact, both under water and on land. The model site in our studies was the Shkota Island and the adjacent water area (Fig. 1). The particular relevance of this work is due to the existing plans for the development of the islands of Peter the Great Bay.

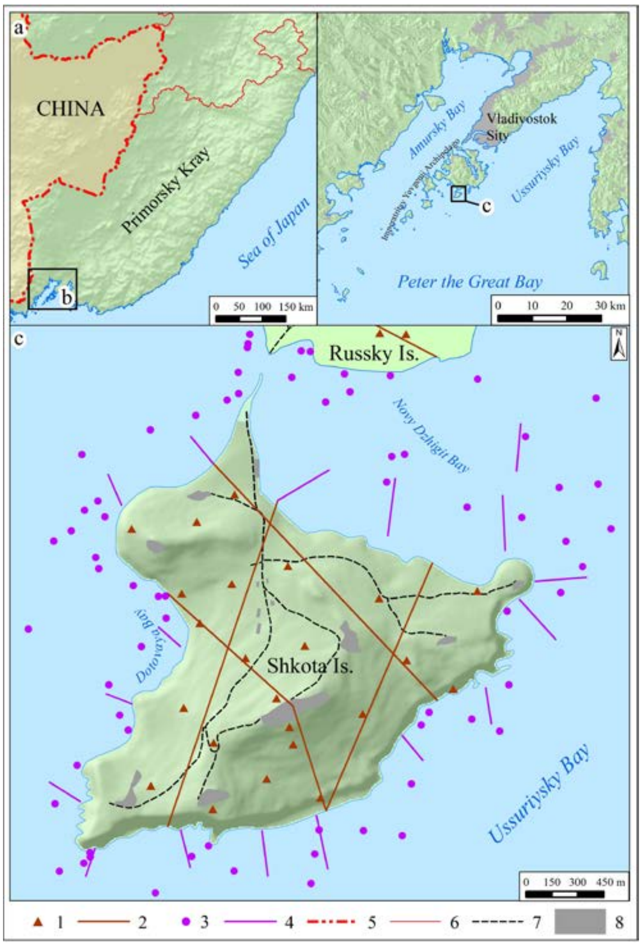

Fig. 1. Geographical location of the study area: a) Primorsky Kray, b) Peter the Great Bay, c) Shkota Island; *1* = ground observation points of terrestrial landscapes, 2 = lines of terrestrial landscape profiles, *3* = basic observation points of underwater landscapes using video equipment, *4* = lines of underwater landscape profiles using diving equipment, *5* = state borders, *6* = regional borders, *7* = roads, *8* = residential areas; source: own elaboration

MATERIALS AND METHODS

The study area is located in Peter the Great Bay (Sea of Japan), it includes the territory of Shkota Island with total area of 251.83 ha, and the adjacent underwater coastal slopes extending from the water edge to depths of 15 to 30 m (the water area is 486.91 ha). The island is a part of the Archipelago of Empress Eugenia and administratively belongs to the city of Vladivostok.

According to the geological structure, the Shkota Island is included in the Muravevo-Danube structural-formational zone with the development of the Lower and Upper Permian volcanic complex. In the Late Pleistocene, when the level of the Sea of Japan was 110–130 m lower than now, all the islands of the Bay were united with the mainland, and the coastline ran along the edge of the shelf. The separation of the islands from the mainland occurred approximately 8–10 thous. years ago as a result of the sea level rise [LYASHCHEVSKAYA, GANZEY 2016].

Relief of the island is low-mountain, with developed local terraces in the coastal zone. The highest point is 147 m. The surface runoff system is practically undeveloped and is represented by several gully formations with temporary watercourses. In the North of the island, there is an elongated accumulative relief structure, continued by underwater foreland stretching for 450 m (tombolo). At the strongest ebb this foreland is surfaced.

In the XX century, the island was actively used by the military. There was an observation post, artillery battery of the Vladivostok (Island) coastal defense sector and military camp. At present time all objects are abandoned and there is no resident population on the island. The island has a system of earth-roads. In general, former military objects cover an area of 7.17 ha (Fig. 1). In the middle of the XX century, dumping works and construction of the road connecting Shkota and Russkiy islands were carried out. After the termination of the operation of military facilities the road was destroyed by waves. At present, the foreland connects Shkota and Russkiy islands only during strong ebb tides.

The shores in the study area are exposed to significant erosion and tectonic dissection and therefore have abundance of coves and peninsulas. The wave activity in the open part of the Ussuriysky Bay is much stronger than in most areas of the Peter the Great Bay. As a result, the abrasive impact on the shores of the local islands is significant.

The climate is monsoon, with an average rainfall of about 800 mm per year, 85% of which is in summer. The average annual air temperature is about +6°C [Gidrometeoizdat 1988]. The minimum water temperature at the surface is observed in January–February (–1.9°C), the maximum in August (26°C) [LUCHIN, KRUTS 2016].

The soils are characterized by peculiarities of the "island" soil formation, the prevailing structure of the soil cover being the burozems [PSHENICHNIKOV, PSHENICHNIKOVA 2013]. According to the geographical-botanical zoning, the vegetation of the island belongs to the southern subzone of coniferous-deciduous (mixed) forests. Most of the species are commonly distributed in East Asia [KOLESNIKOV 1961]. In terms of landscape, boreal and subboreal mid- and south-taiga ocean landscapes with characteristic monsoon circulation of air masses are characteristic for the islands of the bay [ISACHENKO 1985].

In the upper part of the submerged slopes of the shores abrasive benches, outcrops and boulder blocks are widespread. Below, at depths of less than 30 m, fields of different-grained sands with gravel prevail, fine-grained sands and sandy aleurites are located lower.

In terms of biodiversity, Peter the Great Bay is the richest of all marine areas of Russia. In summertime, the temperature regime ensures the inflow of tropical and subtropical fauna, and winter provides optimal conditions for the biota of temperate and arctic latitudes [ADRIANOV 2004; ADRIANOV, KUSAKIN 1998]. Around the islands and at the entrances of the bays the contours of underwater landscapes often form nested rings or arcs, being more pronounced depending on the greater steepness and length of the underwater slopes [ARZAMASTSEV, PREOBRAZHENSKY 1990; MANUILOV 1990].

Methods of integrated physical geographic and geoecological research were applied in this study. The geological and geomorphological structure of the region, soil, bottom substrates, vegetation and benthos were studied.

Terrestrial field work included the establishment of the main and mapping observation points. At the main points, the relief structure of the territory, specifics of the development of geomorphological processes, and characteristics of the lithogenic composition were described. The soil cover was studied using the profile-genetic, morphological, comparative-analytical, comparative-geographical methods and the method of soil keys. Samples of illuvial-humus horizons were selected for subsequent laboratory studies. Geobotanical characteristics are obtained on the basis of taxonomic, ecological, biomorphological descriptions. When the nature of the composing rocks, vegetation and soil cover differed, mapping points were laid. In total, 25 main and 24 mapping observation points were described. In addition, when studying terrestrial landscapes, 4 profiles of sub-latitudinal and sub-meridional directions were laid (Fig. 1). The choice of the profile line was made taking into account that it intersected the most characteristic landforms, geological structures, various plant and soil groups. On the landscape profiles, 42 observation points were described, with an interval of 150 m. The total length of the landscape profiles was 6,137 m, the average length was 1,534 m.

The study of the water area was carried out using an inflatable motorboat equipped with a Garmin ECHOmap 50dv map-plotter, combining the functions of a GPS navigator and an echo sounder. Using light diving equipment, 18 profiles with average length of 160 m and total length of 2,878 m were made. The initial and end points of the transects were positioned by the navigator in the boat. The underwater course was determined by compass, positions of zone boundaries and abrupt facial transitions was recorded according to the lag readings. The descriptions were accompanied by photo and video shooting with iMAX CAM H8 compact cameras and GoPro HERO 4 installed on the diver's tablet. A spot bottom survey was carried out using a BestWill Cr110-7A cable video camera that transmits an image to a monitor screen in a boat. In each of the 69 observation points, the prevailing soil fractions, the dominant vegetation and zoobenthos types were visually recorded. The location of the underwater profiles and reference points observation using the camera is shown in Figure 1.

All sea-based work was accompanied by automatic recording of the echo sounder readings. During the transitions, the movement direction of the boat was chosen taking into account the densest possible coverage of the water area with measurement tracks. The total length of measurements was about 38 km, the number of depth measurements – 8,600 stations.

Classification and mapping. Field data formed the basis for the construction of the classification of terrestrial and underwater landscapes. Classification of landscapes was carried out based on a structural-genetic basis. Classification categories of landscapes from class to specie were separate in accordance with the features suggested by V.A. Nikolaev. The basis for selecting a class was – elements of a mega-relief, a subclass – vertical differentiation of the relief, type – type of plant formation, subtype – subclass of plant formation, geni – type of relief, subgeni – lithology of surface rocks and sediments, specie – plant communities with soil cover (for terrestrial landscapes) and bottom sediments (for underwater landscapes) [NIKOLAEV 1979].

The mapping of land and underwater landscapes and coasts at the scale of 1:25,000 performed with the ArcMap 10.5 software package. For landscape mapping in ArcMap, we used the following set of tools: spatial analyst tools, network analyst tools, data interoperability tools, and others. The mapping included digital elevation model. For terrestrial landscapes data on vegetation and soil cover are used. For underwater landscapes made the map of bottom sediments distribution on submerged slopes using field data with the Surfer 14 software package (Golden Software). Mapping of coastal types made in accordance with the classification of the coast of the Pacific Ocean [KAPLIN *et al.* 1991]. In addition, we used remote sensing data decryption presented by the Google Earth Pro service.

For the statistical analysis of the cartographic model of landscapes, the main structural indicators were used – the area of landscapes, the number of contours and their average area. Comparisons of the landscape structure of land and submerged submarine slopes were carried out using the simulative analysis of the ANOSIM similarity analysis [CLARKE 1993] by comparing the calculated *R*-statistics values. Non-parametric analysis of variance (PERMANOVA) was used to test the reliability of differences, carrying out the decomposition of multidimensional variability contained in the distance matrix [ANDERSON 2001]. The significance of differences at a given level of significance ($p = 0.05$) was evaluated using permutation tests. Statistical data processing was carried out using the PAST 3.20 software [HAMMER *et al.* 2001].

RESULTS AND DISCUSSION

Spatial structure of terrestrial landscapes. Landscape structure of the Shkota Island is formed by 16 morphological units ranked as tract (Tab. 1, Figs. 2, 3). The entire territory of the island belongs to the mountain class of landscapes. Almost 82% of the area of the island is of the low-mountain subclass, which is mainly formed by gentle (113.72 ha) and medium steep (86 ha) slopes on granites and granitoids, in some places granodiorites. Summit and near-summit ridge-shaped and flattened denudation landscapes occupy 2.5% of the island area and are located within the watershed. In the soil and vegetation cover, highly combined poly-dominant deciduous forests of hornbeam, linden, ash, maples predominate on typical burozems (Photo 1a). On the slopes of the eastern and southeastern exposures, low-growing and sparse forests dominate on dark burozems (Photo 1b).

Table 1. Title, area and main characteristics of landscapes of the Shkota Island

No.[1)]	Landscape name	Area (ha/%)	Main characteristics
Terrestrial landscapes			
1	summit ridge broadleaf forests	1.48/0.59	hornbeam, linden, ash, maples on typical burozems
2	summit ridge sparse forests	3.05/1.21	hornbeam, oak, ash on burozems
3	summit ridge semi-shrubs	1.77/0.7	gmelin-lespedeza on burozems
4	medium slope broadleaf forests	61.8/24.54	hornbeam, linden, ash, maples on typical burozems
5	medium slope undersized forests	1.08/0.43	oak, ash, maples on burozems
6	medium slope sparse forests	7.95/3.16	hornbeam, oak, ash on burozems
7	medium slope semi-shrubs	15.17/6.02	gmelin-lespedeza on burozems
8	slope broadleaf forests	71.68/28.46	hornbeam, linden, ash, maples on typical burozems
9	slope undersized forests	5.41/2.15	oak, ash, maples on burozems
10	slope sparse forests	29.97/11.9	hornbeam, oak, ash on burozems
11	slope semi-shrubs	6.66/2.65	gmelin-lespedeza on burozems
12	lowland shrubs	4.95/1.97	shrub-grass on meadow soils
13	ravine broadleaf forests	2.43/0.96	hornbeam, linden, ash, maples on eroded burozems
14	ravine sparse forests	0.17/0.07	hornbeam, oak on dark burozems
15	abrasion ledges sparse grass	29.23/11.61	supralittoral-petrophyte groups
16	coast without vegetation	1.87/0.74	gravel and sand beach
17	anthropogenic territories	7.17/2.85	abandoned objects
Underwater landscapes			
18	slope macrophyte algae	41.9/8.61	perennial macrophyte
19	medium slope macrophyte algae	14.77/3.03	perennial macrophyte
20	slope calcareous algae	227.74/46.77	green, brown and red algae
21	slope foot macrophyte algae	17.14/3.52	green, brown and red algae
22	valley seagrass	181.06/37.19	seagrass communities
23	valley benthic microalgae	4.3/0.88	diatom algae

[1)] Landscape number corresponds to landscape classification (Fig. 3).
Source: own study.

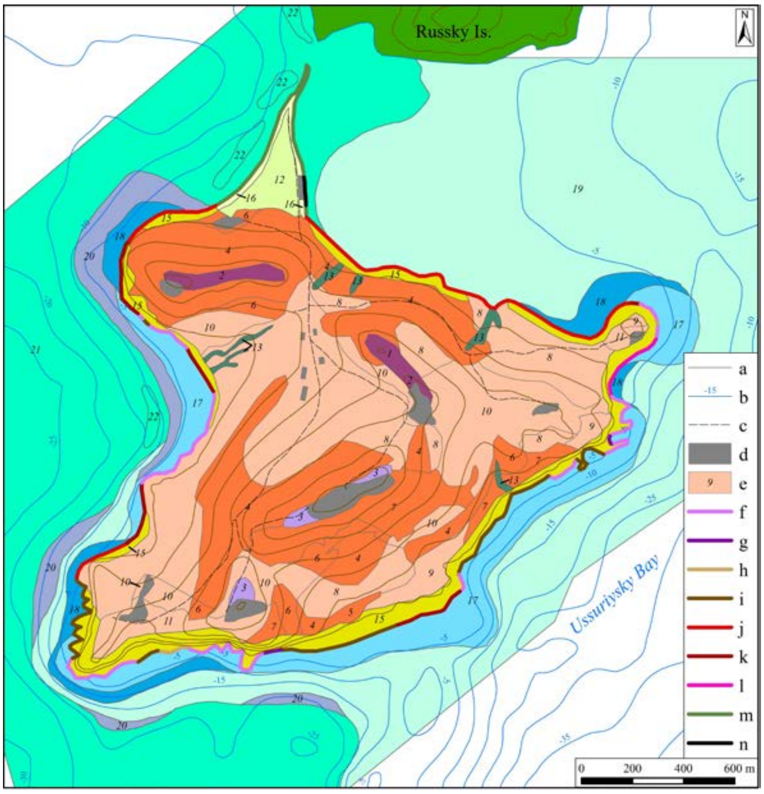

Fig. 2. Terrestrial and underwater landscapes and coast types in the Shkota Island: a) isohypsum (drawn with 20-meter intervals), b) isobaths with depth in meters, c) roads, d) anthropogenic territories, e) landscapes, f)–n) type of coast (legend of type of coast in Tab. 2); source: own study

Terrestrial landscape										
Class			mountain							
Subclass			low mountain					valley	coastal	
Type	subtype	geni	summit and near-summit denudational ridge-shaped	summit and near-summit denudational flattened	slope denudational medium steep	slope denudational steep	coastal accumulative lowland	V-shaped ravine erosion-denudation	abrasion-denudation ledges	accumulative coasts
		subgeni / species	granites and granitoids, granodiorites in same places				sand-pebble and sandy-clay deposits	gravel with sandy-clay deposits	thin sediments	sand and pebble sediments
Forest	broadleaf	highly closed polydominants of hornbeam, linden, ash, maples on typical burozems	1		4	8				
		highly closed polydominants of hombeam, linden, ash, maple on eroded burozems						13		
		undersized on dark burozems			5	9				
		sparce on dark burozems	2		6	10		14		
Brush	shrubs, semishrubs	shrub-grass on meadow soils					12			
		gmelin-wormwood-lespedeza on dark burozems		3	7	11				
Grass	sparse grass	supralittoral groups on stones, partly on marsh soils, and petrophyte groups on primitive soils							15	
Without vegetation and soil cover										16

Underwater landscape							
Class			shallow water				
Subclass			slope			subhorizontal	
Type	subtype	geni	abrasive steep	abrasive medium steep	abrasion-accumulative gentle	transitive accumulative of slope foot	accumulative valley
		subgeni / species	granites and granitoids, granodiorites in some places			gravel-pebble deposits	sand-silt deposits
Lythophilic	macrophyte algae	perennial macrophyte communities	17	18			
		communities of annual green, brown and red algae				20	
	branched and cortical calcareous algae	communities of annual green, brown and red algae			19		
Psammophilic	seagrass	seagrass communities (p. Zostera)					21
	benthic microalgae	benthic communities of diatom algae, epi- and endophages					22

Fig. 3. Legend to the landscape map shown in Figure 2; source: own elaboration

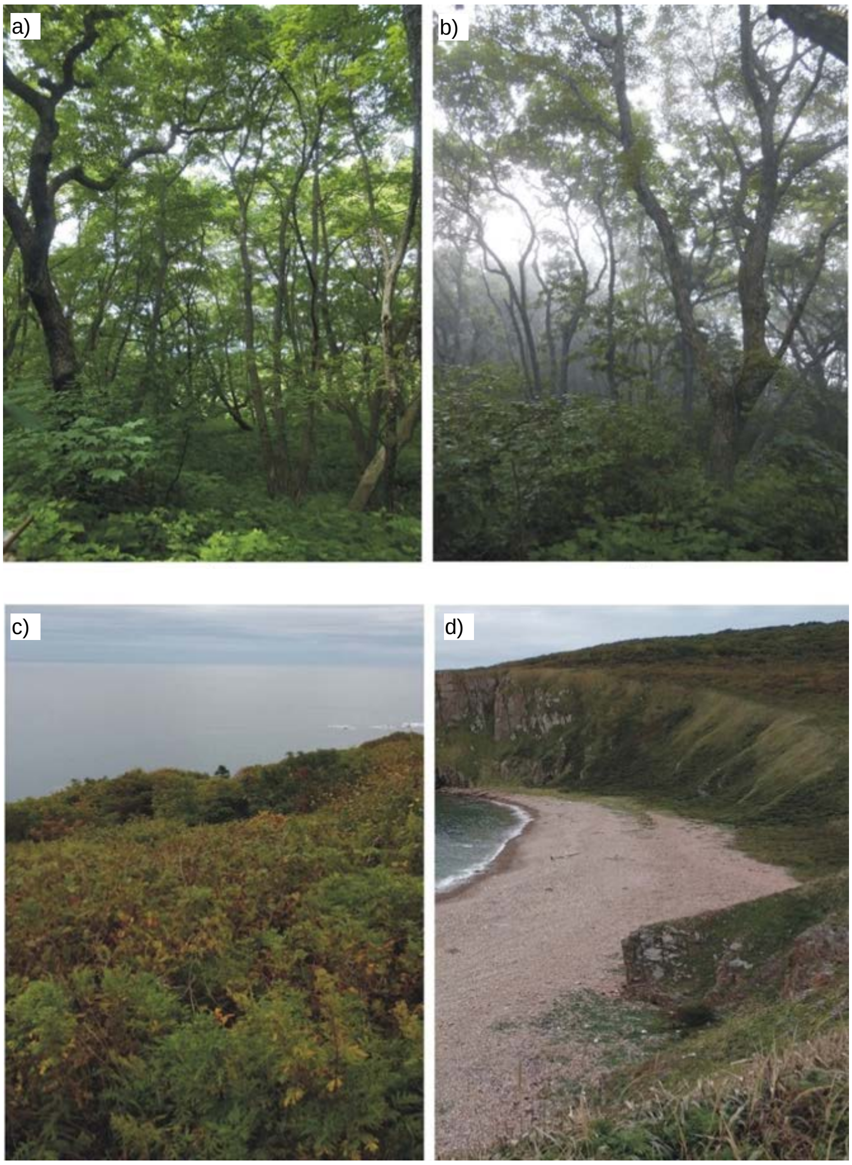

Photo 1. Terrestrial landscapes of the Shkota Island: a) high-combined poly-dominant deciduous forests of hornbeam, linden, ash, maples on typical burozems; b) sparse forests on dark burozems; c) gmelin-wormwood-lespedecia on dark burozems; d) abrasion-denudation with supralittoral groups on stones, partly on marching soils and petrophyte groups on primitive soils (phot. *K. Ganzei*)

The subclass of lowland landscapes also includes a genus of coastal accumulative lowland landscapes on sandy-pebble and sandy-argillaceous sediments with shrub-grass communities on gray-humus soddy soils that form the northern tip of the island.

The valley subclass of landscapes is represented by V-shaped ravine erosion-denudation complexes on gravel with sandy-clay sediment (1.03% of the island area). For ravine-gully stands, the spread of highly closed polydominant deciduous forests on eroded burozems is characteristic. The soil cover, due to the increased skeletal character of the soil profile (up to 90% of the soil mass) and the steepness of the slopes, is characterized by the active development of erosion processes, especially during the period of heavy rainfall (July–August). As a rule, the litter layer and partially humus horizon are demolished by torrent streams, and in some cases the illuvial part of the profile is also exposed. In the eastern part of the island, forests in ravine-gully complexes acquire sparse and low-growing species.

The subdominant on the island is the coastal subclass of landscapes (12.35%), which is mainly formed by abrasion-denudation benches with thin sedimentary deposits with supralittoral groups on stones, partly on marching soils and petrophytic groups on primitive soils (Photo 1d). They are stretched in a narrow strip along most part of the island coast, and represent the immediate zone of contact between land and sea.

With depth, the coastal slope becomes more gentle, the relief amplitude decreases; rocky outcrops and blocky ruins are replaced by boulder area and finely clastic material (Photo 2b). In the lower part of the side of the slope, abrasion-accumulative landscapes are registered (46.8%). The phytobenthos is represented by cortical and branchy forms of calcareous crimson; echinoderms dominate in zoobenthos – starfish, sea urchins and small mussel druses.

The sub-horizontal subclass of underwater landscapes (41.6%) is characterized by the absence of sharp relief changes, soils with finely clastic material and sand. For a kind of landscape transit-accumulative with gravel-pebble material and coarse sand (3.5%), phytobenthos is represented by sparse thalli of green, brown and red algae. The composition of zoobenthos determines the forms characteristic of both rocky and sandy substrates. Echinoderms,

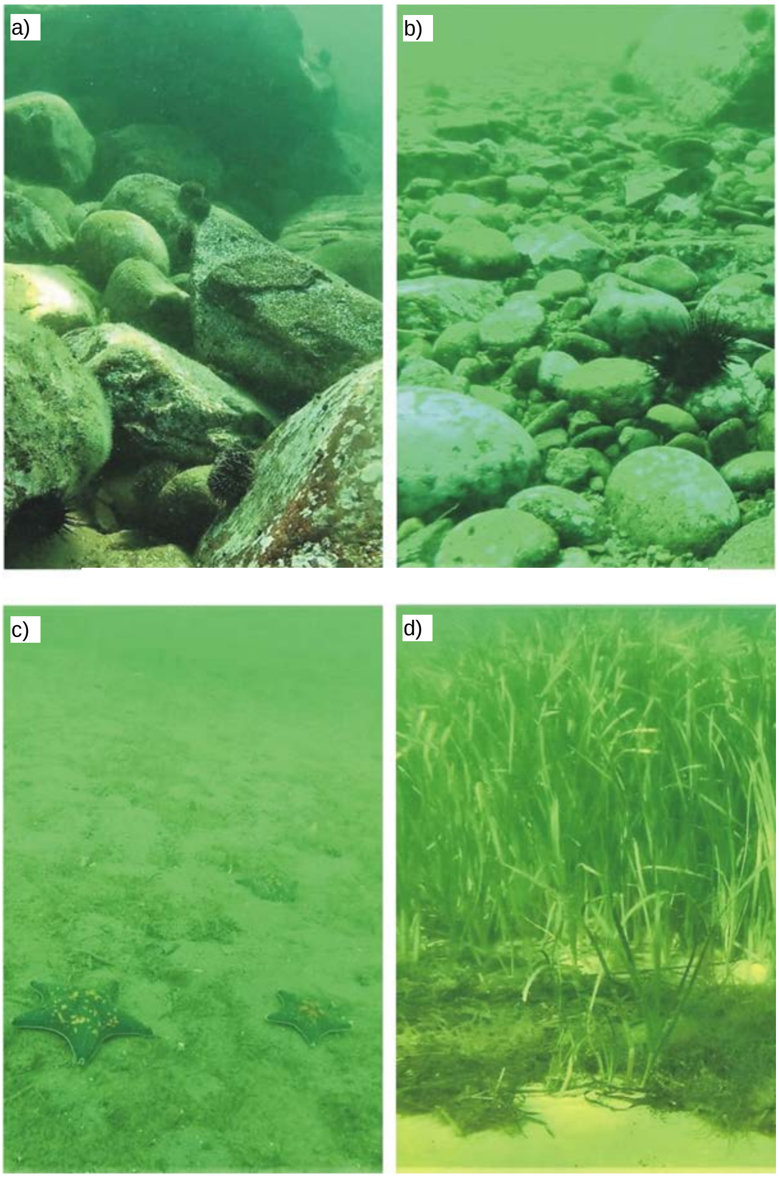

Photo 2. Underwater landscapes: a) vertical rock surfaces, bedrock outcrops with small macrophytes; b) boulder area with cortical calcareous algae; c) accumulative sandy-aleuritic plain with benthic microalgae; d) thickets of seagrass on a subhorizontal sandy surface (phot. *A. Lebedev*)

clams, and anemone are abundant. Aggregations of mussels are common and purple ascidia are common. The surface of the sandy substrate is highly bioturbated, indicating abundant infauna.

The accumulation-flat landscape forms the northwestern part of the water area with medium-grained and fine-grained sand mixed with shell detritus (38.1%). In coastal shallow waters, the bottom surface is relatively flat, with increasing depth in the microrelief, numerous traces of the infauna life activity appear and sandy substrates are characteristic under conditions of weakened hydrodynamic impact of polychaeta settlement (Photo 2c). Starfish and urchins are common on the sand, but their density is low. It increases in places where debris material accumulates. In this part of the water area on sandy soils with depths of up to 2.5–3.0 m, compact settlements of Zostera are common, but dense thickets of water grasses forming significant landscape fields in this area have not been registered (Photo 2d).

When analyzing the spatial structure of the studied landscapes, the dependence on geological and geomorphological structure of the area and the patterns of distribution of hydrodynamic effects on the coast and underwater slopes is obvious. The underwater slopes of the southern and eastern exposure, adjacent to the high abrasion windward shores of the island, are characterized by openness and, accordingly, high gradients of the main hydrodynamic parameters. Here landscapes of the slope subclass are arranged in successive stripes. With increasing depth and flattening of the slope sub-horizontal landscapes prevail in the structure. At the same time, on the underwater slopes of the western and northern expositions, a rapid transition to transit-accumulative and accumulative types of landscapes is characteristic.

Types of coast. On the Shkota Island, four types and nine subtypes of coasts were identified (Figs. 2, 3, Tab. 2). The total length of the coast is 9.42 km. The island's abrasion-denudation coasts predominate at 5.55 km (58.9% of the total length of all coastline). The coast with steep cliffs is located in the East and South-West of the island and has a length of 2.06 km. The shores with a steep coastal ledge stretch for 3.49 km, and are located in the North, West and,

Table 2. Coastal types of the Shkota Island

Coastal type	Coastal ledge type	Beach type	Marked at Figure 2	Length (km/%)
Abrasive	abrupt (45–90°)	not available	f	2.48/26.37
		narrow and mostly boulder	g	0.12/1.27
Abrasive-denudation	abrupt and steep (40–60°)	narrow and pebble-boulder	h	0.1/1.48
		average width pebble-gravel-sand	i	1.92/20.38
	steep (25–40°)	narrow pebble-gravel-sand	j	2.23/23.67
		average width pebble-gravel-sand	k	0.97/10.29
		wide pebble-gravel-sand	l	0.29/3.18
Accumulative		pebble-gravel-sandy full profile	m	1.1/11.67
Man-made		not available	n	0.16/1.69
Total				9.42/100

Source: own study.

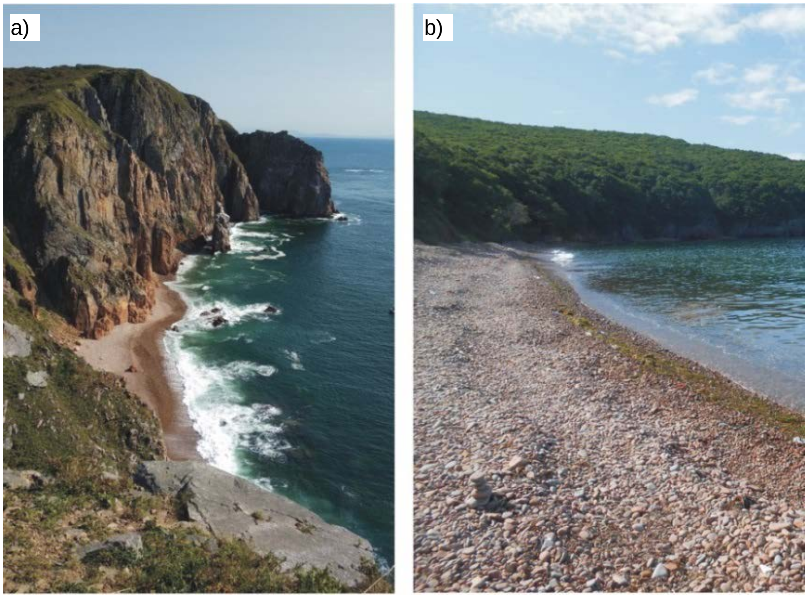

Photo 3. Types of coast of the Shkota Island: a) abrasive, steep, with a narrow and predominantly boulder beach – eastern coast; b) abrasion-denudation steep with medium width of beaches, pebble-gravel-sandy – western coast (phot. *V. Zharikov*)

fragmentarily, in the East of the island (Photo 3). The abrasion-denudation type of the coast is characterized by the destruction of rocks and the accumulation of products of destruction in the beach area and on the underwater slope.

Abrasive coasts with a steep type of coastal ledge subdominate on the island. Their length is 2.6 km (27.64%), and they are distributed mainly in the West, South-West, and East of the island. For the abrasion type of coast, no accumulation of rock destruction products in the coastal zone is noted. Accumulative coasts are present only in the North of the island and encircle the accumulative relief form, which connects the underwater foreland with the Russian island. The length of this type of coast is 1.1 km (11.67% of the total length of all coast). Manmade coast, which is an abandoned reinforced concrete structure used for fishing purposes, is also locally distributed on the island. This type of coast extends for 0.16 km (1.69%) – Table 2.

The main feature of the terrestrial and underwater natural complexes of the Shkota Island is their exposure differentiation, which is due to the monsoon nature of the climate and the intensity of the hydrodynamic impact on the shores and underwater slopes. For terrestrial landscapes, due to the intense impact of the southeastern winds during the growing season and the droplet-pulsating effect of sea water on the slopes of the southern and eastern exposures, there is a spread of sparse and low-growing deciduous forests, shrubs and semi-shrubs on dark brown soils, and highly dense deciduous forests on typical burozems on the slopes of the western and northern exposures.

The development of active abrasion is peculiar to the underwater landscapes of the eastern and southern expositions. As a result of landslide-scree processes natural to abrasion and abrasion-denudation types of coasts of the eastern and southern exposition, coarse detritus material enters the coastal zone, which plays an abrasive role. As the depth increases, the hydrodynamic impact decreases with a transition from abrasive to abrasive-accumulative landscapes. A different picture is noted on the western side of the island. Less active wave effect results in weaker development of landslide-scree processes, which leads to slower development of the abrasive type of underwater landscapes, with their transition to transit-accumulative and accumulative landscape types. The northern coast of the island, adjacent to the Novy Dzhigit Bay, is protected from the active wave action formed by an abrasion-accumulative type of landscapes.

Despite prevailing abrasion shores on the Shkota Island, the intensity of dangerous geomorphological processes (for example, landslides) is strongly differentiated between the coasts of the southeastern and northwestern orientation, which is also associated with a high intensity of hydrodynamic effects from the Ussuriyskiy Bay.

According to IVANOV and SHAPOVALOVA [1997] we distinguished zones of intense and weakened interaction of land and sea. We also suggest to allocate a zone of moderate interaction between land and sea. In the study area, the zone of intensive interaction includes abrasion-denudation and accumulative aerial, abrasion, and abrasion-accumulative aquatic landscape types.

From the sea this boundary passes approximately along the 10 m isobath. It is the focus of maximum stress of the system-forming and system-binding processes of the coastal geostructure of the Shkota Island. The effect of moderate material-energy interaction of land and sea for the aerial part of the system is reflected by the impact of the southeastern winds and impulverization of sea water resulting in the asymmetry of the soil-plant complexes. We noted this process above. For the aquatic part of the system, similar moderate effect is recorded for the abrasive-transitive landscape type.

The zone of weakened interaction includes terrestrial types of landscapes with highly closed polydominant deciduous forests located on the slopes of the western and northern expositions and an underwater accumulative plain type of landscapes in the western part of the studied water area. The northern coast of the Shkota Island is characterized by the absence of underwater landscapes influenced by the maximum stress processes, due to weak hydrodynamic processes compared with the eastern coast. Due to the weak development of landslide-scree processes, local abrasion coast type with steep coastal ledge is characterized by narrow pebble-gravel-sandy beach.

As Figure 4 shows, the width of the zone of intense interaction on the southwestern coast averages 170–180 m, on the western coast 80–100 m, on the northern coast 30–45 m. The asymmetry of the zones of moderate and weakened interaction is clearly identified.

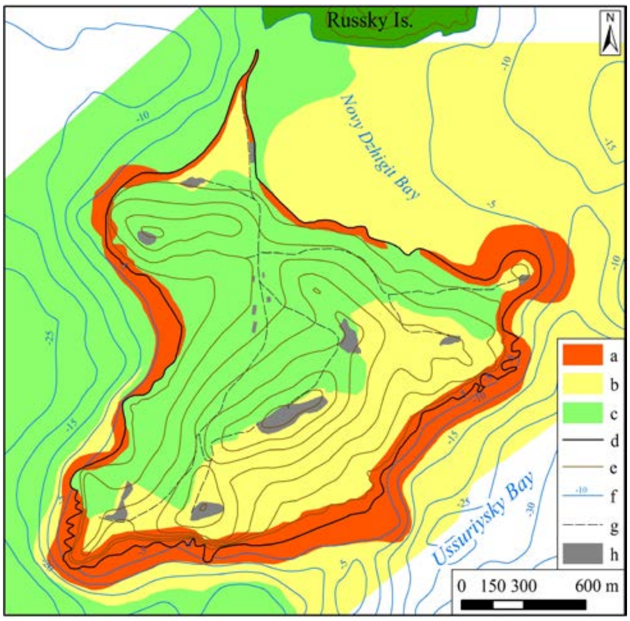

Fig. 4. Zones of interaction of aerial and aquatic landscapes: a = intense, b = moderate, c = weakened; d = shoreline, e = isohypses (marking every 20 m), f = isobaths indicating the depth, g = roads, h = residential areas; source: own study

The value of statistics *R* –0.321 obtained by comparing the structural characteristics of land landscapes and underwater landscapes (ANOSIM test) indicates the difference between intergroup and intragroup distances (the probability of equal distances $p = 0.027$). The results of the PERMANOVA test lead to the same conclusion ($F = 6.894$, the probability of no differences between groups based on estimates of the variance is $p = 0.019$). The average land area in the sample was 15.29 ha (the confidence interval of the general average is from 5.41 to 26.03 ha). On the shallow water, these figures were significantly higher: 81.15 ha ($14.45 < \mu < 149.36$ ha). These data indicate more complex landscape structure of terrestrial part related to submarine slopes and plains. Obviously, this is a consequence of the greater amplitude and complexity of the relief and, consequently, the greater contrast of the natural conditions of island territory compared to the nearby shallow water landscape.

Most of the research in the landscape science is focused on the terrestrial environment, mainly ignoring underwater landscapes. Works based on a comprehensive spatial analysis of landscapes and seascapes are still few in number. Thus, multivariate analysis of landscape metrics was used to identify differences between landscapes and seascapes and to compare the effects of anthropogenic impact in terms of spatial heterogeneity of ecosystems in the Bay of Naples. Significant differences in metrics of diversity and heterogeneity between the sites were revealed between land and sea. These results indicate that seascapes are less fragmented than landscapes in this highly pressed aquaterrestrial system [APPOLLONI *et al.* 2018]. Similar results were obtained in our study.

It is generally accepted that the two most effective environment protection activities for coastal marine ecosystems are introduction of marine protected areas or reduction of land-based threats. Active recovery of aquatic systems is generally considered a low priority option, in part because of high costs and low success rates. A model developed for marine grass communities and adjacent watersheds in Queensland, Australia, has shown that restoration of seascapes in the long term may be the most cost-effective approach to conservation of coastal ecosystems [SAUNDERS *et al.* 2017]. Coastal zones are a case where consideration of the relationships between land and sea ecosystems needs to be integrated into coastal zone management [STOMS *et al.* 2005; TALLIS *et al*. 2008]. Our results demonstrate the need to plan simultaneous conservation of land and marine systems and provide the necessary data for this. Our findings provide additional support for coordinated decision-making and management actions in land and marine systems.

CONCLUSIONS

Based on the comprehensive study of terrestrial and underwater landscapes, types of coast of the Shkota Island, and large-scale mapping and statistical research, features of the spatial organization of aerial and aquatic natural complexes were described. As a result of mapping, 22 types of landscapes have been identified, 16 of them are terrestrial, and 6 are underwater. The shores of the Shkota Island are formed by four types and nine subtypes with the dominance of abrasion-denudation and abrasion types of coasts.

A specific natural feature of the study area is the exposure differentiation in the structure of landscapes between the southeastern and northwestern parts of the island. It occurs due to the monsoon climate and the intensity of hydrodynamic effects on the shores and underwater slopes. The results of field and mapping works formed the basis for the selection of zones of intense, moderate and weakened interaction of land and underwater landscapes. The spatial arrangement of the interaction zones is clearly illustrated by significant exposure differences. Moreover, data from the statistical analysis of mapped landscape model reflect that a quantitative comparison of the landscape structures of terrestrial part and shallow water surrounding of the island based on the map characteristics of the elements of landscape differentiation indicate structural and genetic heterogeneity of the geostructure of Shkota Islands through combination of landscape-forming factors.

The presented example of studying the aerial and aquatic natural complexes, the assessment of their spatial and material interaction is the basis for identifying priority types of coastal-marine environmental management and spatial planning. This will ensure compliance with the balance between environmental requirements and proposals of various plans for the use of the territory, creating a basis for making decisions about the acceptability of various intentions of nature users.

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