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SAND DUNES ALONG THE BULGARIAN BLACK SEA COAST

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Abstract

The main goal of the present study was to develop an inventory of the sand dunes along the Bulgarian Black Sea coast in an attempt to identify dune locations and distribution, as well as to describe various types, their genesis and current morphodynamical state. For this purpose an indicative GIS-based map of sand dune locations along the coast was produced using a data derived from 1:25 000 scale topographic maps and filed observations/surveys. Thus, an initial GIS database for sand dune fields situated at the Bulgarian coast has been provided and this could be further easily updated with new coastal data and spatial information.

Based on the results obtained from the study and the produced GIS map about 20 locations of different types of dune fields were identified around the Bulgarian coast: some at the northern part, partially at the middle one, but the numerous dune complexes exist along the southern coastline. In the near past sand dune formations were widely distributed around the coast, however, at present the remaining dune landscape comprises only 10% of the entire coastline and it is continuing to decrease. Although sand dunes are unique priority habitats and protected sites they are presently under increasing pressure and overuse due to constantly growing population and expanded human activities in the coastal zone of Bulgaria. In the context of current problems there is an increased demand to inventory the coastal dune systems and to identify those

areas most sensitive to natural hazards and human impacts. Thereby, preservation and proper management of the sand dunes first require understanding their behaviour and identifying the major factors responsible for dune degradation.

Key words: coastal geomorphology, GIS mapping, foredune, sand dune destruction, sediment sources

1. Introduction. Sand dunes are important features along the world coastlines as they play fundamental role in sediment balance, in buffering between waves and coasts, and they are also unique environments with high diversity of species. With changes of the global climate and expanded coastal industrialisation, sand dunes and beaches have been exposed to many natural and anthropogenic hazards leading to their constant destruction. As sea level rises and coastline becomes subject to ever more increasing change, it is recognised that the behaviour and sensitivity of sand dunes must be better understood [1].

In this regard, the study presents an inventory of the sand dunes along the Bulgarian Black Sea coast in an attempt to examine various dune types, genesis and distribution, and to highlight their current morphodynamical state. In support of this an indicative map showing the locations of dune fields along the coast was developed with the help of Geographic Information System (GIS) methodology. In this way, using various data sources and spatial information, an initial GIS database for existing sand dune types has been provided and it could be further easily updated as new coastal data become available. The research also flags an attention on the increased dune degradation as a result of accelerated human activities along the Bulgarian coastal zone, particularly over the last decade.

2. Definition of coastal sand dunes. Coastal sand dunes are large accumulation forms as a result of similar processes and in general similar shapes and patterns to dunes on inland deserts. The fundamental role in both cases is playing by the abundant sediment supply and the wind to transport it. Prevailing winds or diurnal sea breezes provide the typical transport mechanism for sand-sized sediment on most worldwide coasts [2]. Coastal dunes differ from inland (desert) dunes in that they are subject to a wider variety of processes, including wave action and vegetation, which influence their size, evolution and persistence. Coastal sand dunes are more often formed along gently sloping dissipative beaches than behind steeper, coarser and narrower reflective beaches [3]. The process of dune formation is closely related to winds action and sediment supply. Much of the wind-blown sand tends to accumulate just landward of the active backbeach. This transported sand could be stopped from further movement by any type of obstruction that could exist, like bedrock cliffs, vegetation, already existing dunes or even human constructions (buildings or seawalls). Once the initiation of eolian

sediment accumulation begins, it continues unless formation conditions change, such as loss of sediment supply, the destruction of the stabilization factor or wave-induced erosion. The absence of intense storms or abundant supply and a regular mechanism for delivery of the sand potentially could form a dune. Dunes growth and shaping are then related to a source of sand that can be moved by wind, wind flow characteristics, rates of aeolian transport and patterns of erosion and deposition.

Generally, there are three main dune forms:

1. Foredunes or incipient dunes;
2. Parallel dunes;
3. Transgressive dunes (long mobile dunes and migrating inland) – extensive on desert coasts and humid regions such as the Polish Baltic coast for example.

Foredunes and parallel dunes are the most common landforms and they are generally supplied with sand from adjacent beaches. Foredunes are formed when wind-blown sand has been trapped by vegetation behind a beach. Such dunes may be cliffed by storm wave erosion and subsequent formation of more foredunes may result in the evolution of parallel dunes. Where backshore dunes are not retained by vegetation (or where the vegetation cover is destroyed) they drift downwind as transgressive dunes [3]. There are geographical variations in the plant species that act as pioneer colonists and foredune builders. Parallel dunes are sometimes called secondary dunes, since the foredune is the first dune located at the backshore of the beach, and parallel dunes are located behind the foredune.

Coastal dunes have formed over a variety of timescales, but most of them have been shaped in the Holocene from sand supplied to beaches from the sea floor (notably marine transgression) and alongshore sources such as cliffs in soft sandstone or glacial drift deposits. On some coasts the Holocene dunes overlie, and are backed landward by dune formations that originated in the Pleistocene, some of which may have formed during phases of falling sea level, when of onshore winds swept sand from the emerging sea floors [2, 3]. Dune size is dependant on the input of sand-sized sediments (0.1–0.3 mm). Dune sands have similar characteristics to the beach sands from which they have been originated and generally consist of quartz, feldspar and calcareous particles (including *foraminifera* and *bryozoa* and comminuted shells and corals, sometimes with heavy minerals).

Dune orientation generally reflects the dominant wind direction [2, 3]. When the prevailing winds are onshore then strands of transgressive dunes form parallel to the coast and they move inland. The longitudinal axis of parabolic dunes that form is perpendicular to the beach line and these dunes also advance landward, but more slowly. In case the strongest winds are N and NE and the coastline orientation is also NS, the axis of dunes is parallel to the beach, and transgressive dunes move from north to south. Sand dunes can also be classified as active (mobile) or stable (fixed), as it mostly depends on the presence of plant species

building dune vegetation, which play a major role in stabilising sand and reducing winds strength. In active dunes, sand movement produces erosion at certain areas and accumulation at others, thus forcing dunes to advance or migrate. There could be also semi-mobile zones where plants are beginning to retain the sand, and finally there are stable or fixed dunes located inland that are entirely covered with vegetation [4].

3. Study area and current state of knowledge. The Bulgarian Black Sea coast has a length of 412 km [5] with large variety of sandy beaches and dune formations located along the shoreline. In general, sand dune systems occur behind larger beaches or in small inlets between erosion coastal sections, where their development has been favoured by the ruling factors: coastline orientation, wind direction and sufficient sediment supply. Commonly, such beach-dune systems or separated dunes consist of beaches, foredunes, parallel mobile and more stabilized or fixed dunes located landward.

Sand dune formations are not homogeneously distributed along the Bulgarian Black Sea coast. They are mainly formed at its northern part, partially at the middle one, as the numerous dune complexes exist along the southern coastline. Although there is a large dune distribution, they have poorly been explored and described from geological and geomorphological points of view. Moreover, there lack now references about dune genesis and categorized types or detailed studies on morphodynamical dune behaviour. Ones of the earlier observations and researches are these of [6] regarding general description of sand dunes as accumulative forms and their developments along the Bulgarian coast. The authors pointed out the leading role of winds for sand dune accumulation and partially described their composition. The W and NW winds mostly predominate along the northern Bulgarian Black Sea coast, while at the southern coast the dominant winds are from N and NE direction, and in summer the E onshore winds mainly rise along the Bulgarian coast.

A more recent study reported on dune genesis and formation at the Bulgarian coast [7], based on archaeological evidences from the necropolis at the Kalfata plot in the vicinity of the ancient Greek colony of Appolonia Pontica (modern Sozopol). The research suggests that sand dunes had probably developed during the late Holocene (in the last 7000–5000 years) and their formation had started when tentative changes of climate to warm and humid weather had commenced. Floods on the continent strongly eroded the soil cover and formed huge quantities of river sediments. Thus, for example the area of Harmanite Bay south of Sozopol was inundated by sand. Strong winds had began to blow in the last 3000 years after the climate changes had occurred and led to dune formation by sand accumulation and its blowing westward forming dunes on the land. Similar movement process of marine sands landward had favoured dune developments at many other sites along the ancient Western Black Sea coast: around the towns of modern Sozopol,

Nessebar and Golden Sands resort, at Kamchia River mouth and Ropotamo River, at the areas of Shabla and Durankulak, and north at the Romanian coast. At the low-lying areas, as it is the case of Sunny Beach resort, the aeolian deposits had spread far west forming a large strip of several parallel dunes unless the conditions of wind action had changed.

Another similar study by [8] has focused on dune formation along the Bulgarian coast during the last 3000 years. The authors distinguished two types of dune sands along the southern Bulgarian Black Sea coast: 1) Dune sands formed without resistance, like the isthmus of Sozopol, or the dune sand at the mouth of Veleka River; 2) Dune sands formed against resistance, like the beach of Harmanite Bay. The latter shows strong dune accumulation during cold periods and weak influence of a 176-year warm period with rain and erosion of volcanic rock material which became mixed with dune sand. Besides a small amount of shell fragments, the dunes formed during the cold climatic periods contain a high amount of quartz with a grain-size maximum between 0.5 and 1.0 mm. Dune sand from warm periods is mixed with eroded volcanic rock material having dark colour and a grain-size maximum of about 2.0 mm.

Other research by [9] provided a detailed field investigation on the psammophytic vegetation along the Bulgarian sandy beaches and dunes. In general, there are geographical variations in the plant species that act as pioneer colonists and foredune builders. The floristic complex of the Bulgarian Black Sea dunes includes more than 200 taxa of higher plants. Parts of these are typical psammophytes (*Eryngium maritimum* L., *Euphorbia pepelis* L., *Leymus racemosus* (Lam.) Tzvel. subsp. *sabulosus* (Bieb.) Tzvel., *Ammophila arenaria* (L.) Link., *Crambe maritima* L. and others). They form almost the entire vegetation of the beaches and the shifting (mobile) dunes. A predominant part of the taxons has a higher ecological amplitude and wider distribution. Most frequently, they are related with fixed dunes. The hygrophytes grow in the lower parts of the dunes and compose a small fraction of their vegetation. It has been found as well that the coastal vegetation of the Dobrudzha coast is quite different to the one south of the Golden Sands resort and it should be considered that the northern and southern dune complexes have specific flora and vegetation. The basic reason is the difference in climate conditions along the coast. On the basis of this vegetation survey the structure of the Black Sea sand dunes as a whole could be optionally divided into two main groups [9]:

i) the first group includes dune systems, which consist of beach and shifting dunes with unstable sand. Such typical dunes are distributed near the areas of Durankulak, Shabla, Krapetz and at other sites;

ii) the second group includes also regions with fixed dunes, found beside shifting dunes. Such dunes exist near the Kamchia River mouth and the rivers of Ropotamo and Dyavolska (Primorsko town), at the area of Sunny Beach resort – town of Nessebar, and at other sites.

In addition to wind action other factor playing important role in dune shaping is an abundant sediment supply to the beach areas. The major sources of sediment material to the coastal zone of Bulgaria have been determined to be: river solid discharge, cliff erosion and wind-blown material from the continent. Large sediment amounts were supplied from the cliff, but in result of implemented coastal defence activities the input of eroded material has decreased [10]. Over a 50-year period (1960–2008) the volume of sediment material has been reduced from 1 344 000 to 221 000 m³, the length of erosion cliff has shortened from 271 km to 219 km and the average rate of costal erosion has decreased from 0.26 to 0.08 m/y. The total mass of river solid discharge along the Bulgarian Black Sea coast is estimated to be 1 076 300 Mg/y, but it should be pointed out that not the entire sediment river load might enter the sea and a few amount is deposited at the river mouths, lagoons and firths. The amount of solid discharge of rivers that directly inflows into the Black Sea has been estimated to be 780 600 Mg/y. Considering the role of aeolian drift in the total sediment budget of the coastal zone, the composition of wind-blown material should be taken into account. For the coastal area most important is the sand with median grain-size $d > 0.1$ mm, while for the shelf it is the air-borne fine dust of silted (aleurite-pellite) fractions. In contrast to eroded material and river solid discharge, the role of aeolian drift in the sediment budget of the Bulgarian coastal zone has been evaluated to be smaller. If we assume the average seaward sediment transport found for the Ukrainian coast to be similar to the one for the Bulgarian coast, the amount of wind-blown material by aeolian drift could be considered as 15 100 Mg/y [10].

4. Data used and methodology. For the purposes of making a sand dunes inventory and a map, indicating their distribution/location along the Bulgarian Black Sea coast two types of data were collected: data of sand dunes from topographic maps in scale 1:25 000 and data from field observations and surveys. In addition, for more detailed description and visualisation of main dune types, a number of digital photos were made at certain parts of the Bulgarian coast. Various information sources were also provided, such as scientific publications/books, independent sources that were found, and interviews with local individuals. A preliminary survey along the coast, literature overview and all published/recorded coastal data were utilized to determine dune landscape and to trace out the locations of sand beaches/adjacent dunes and then their spatial distribution along the Bulgarian coast. All sand beaches and dunes are symbolized on the topographic maps and this allowed their identification. It should be noted, however, there are not clearly presented boundaries between beaches, dunes and inland territories on the maps. Therefore, dune locations on the indicative map of distribution were remarked together with adjacent sandy beaches. The maximum dune sizes in height were also taken from the topographic maps, which gives the possibility to determine various dune types and the locations of the larger dunes.

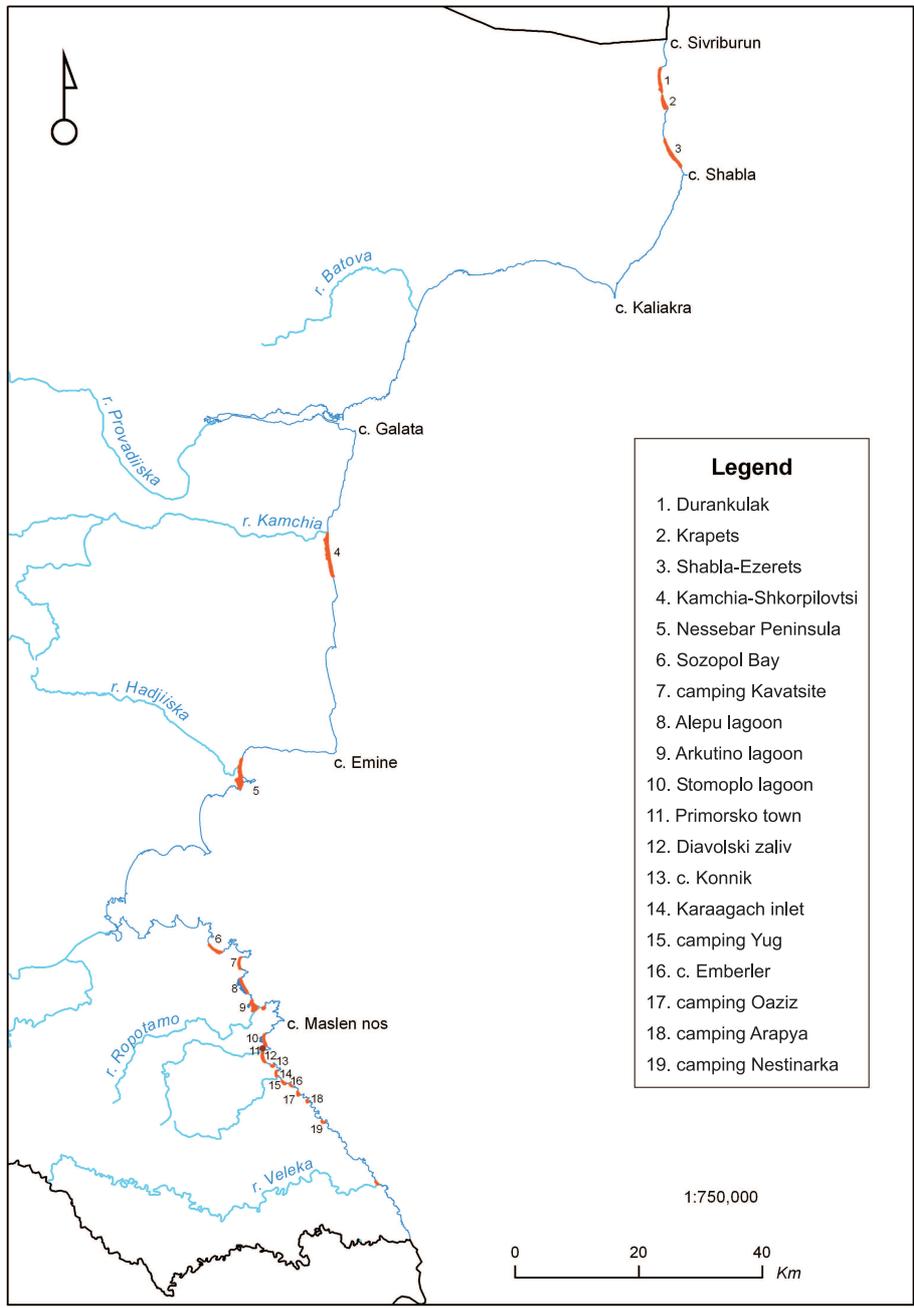


Fig. 1. Sand dune distribution along the Bulgarian Black Sea coast



Fig. 2. Foredunes formed behind Durankulak beach – 2009 (by Hristo Stanchev)



Fig. 3. Large dune ridge parallel to the shoreline at Krapets beach – 2009 (by Hristo Stanchev)



Fig. 4. Part of a large dune complex at the lagoon of Alepu



Figure 5. Dune field north from town of Primorsko (by <http://www.primorsko-bg.com/>)

Before mapping sand dunes along the coast, all raster maps were scanned, geo-referenced and digitalized with the help of GIS – ArcInfo 9.2. First, by the Arc GIS layer of the polygon type was created as a shape file in Arc Catalog. After this operation, polygons included all situated sand dune formations along the coast were generated. Applying then XTools Pro GIS extension the areas and lengths of all dunes were estimated. For more detailed study and to highlight the current state of sand dunes along the coast a number of field observations have been carried out, as the dunes of the northern part of the Bulgarian coast has recently been investigated – in September 2009 a field survey at the coastal session between capes Kartalburun and Shabla was carried out.

5. Sand dunes distribution along the Bulgarian Black Sea coast.

Sand dunes are widely distributed along the Bulgarian Black Sea coast as they occur at many sites. Depending on the dominant onshore winds, geology and orientation of the coastline at different sections dunes distinguish by their formation, type and size, as well as by the grain-size composition. In general, there are sites with developed beach dunes and mobile (active) foredunes, and more stabilized grassed dune fields, located at a large distance into the land.

On the basis of data processed and analysed in GIS environment, an indicative map of sand dune distribution along the Bulgarian coast was produced and a number of 20 sand dune and/or beach-dune systems locations were identified (Fig. 1). A few larger dune fields are situated at the northern part of the coast between the capes of Durankulak, Krapets and Shabla, around the large firth area of Kamchia River mouth, but the numerous dune complexes are mainly situated at the southern coast (near the town of Nessebar, the lagoons of Alepu, Arkutino and Stomoplo).

In north–south direction larger dune systems are developed at the coastal section between the capes of Kartalburun and Shabla, and in particular near the beach of Durankulak, north from the cape Krapets along the sandy beach and at the coastal area of Shabla–Ezerets (Fig. 1). At certain sites dunes behind beaches are small in height (about 2 m in average), mobile and sparsely covered with a specific dune vegetation. According to the field observations in this section, here the sand dunes are composed of very fine and well sorted sand, almost similar to those of the beach and having high content of broken shells, i.e. CaCO_3 (Fig. 2).

North from cape Krapets there are large dune fields represented by beach dunes (foredunes) and wide complex of fixed stable dunes located behind the coastline and spreading into the land at a distance of 400 m. These stabilized dunes are densely grassed with specific vegetation, as well as at some sites there are forested dunes. They reach a maximum height up to 10–15 m and the composing sand is fine and yellow in colour. Behind Krapets beach a large parallel dune ridge is formed along the middle and north part of the shoreline, having maximal height of 4 m. This dune ridge spreads along the beach at a distance of almost

2 km and it passes landward into stabilized grassed dune field distributed at a distance of 500 m (Fig. 3). Along the coastal area of Shabla–Ezerets the largest dune complex north from cape Kaliakra is located, as it spreads over a length of 5000 m and a total area of almost 1 km². However, it should be mentioned that most of these large dune fields have been overbuilt and concreted during the construction of camping Dobrudzha.

Next area along the Bulgarian coast with well developed dunes is situated in the region south of Kamchia River mouth (Fig. 1), where the existing sandy strip divides the large Kamchia firth from the sea [11]. The Kamchia River site comprises the best preserved flooded forest along the Black Sea coast named *longoz*, which is a unique example of such habitat in whole Europe [12]. At this section, between the mouths of Kamchia and Fandakliyska Rivers, the largest dune complex (grey dunes with wet dune slacks and forested dunes) at the Bulgarian coast is located with a length of 7180 m and area of 2 km² and they are also priority habitat for conservation in the European Union. At the north part, near to Kamchia River mouth, there is a large dune bar parallel to the coastline and having a maximum height of 6 m. Since the coast here is exposed to the E and NE winds, a number of sand dunes with maximum height of 8 m has been formed landward just behind the bar [6, 11]. Similar climate conditions (dominant winds from E, NE and N directions) have also shaped a specific dune landscape around the longest beach of Shkorpilovtsi, as it distinguishes with large foredunes and parallel dunes landward.

In south direction larger sandy beaches and their dune systems are distributed along the coast of two small bays, situated on the north and on the south of the Nessebar Peninsula (Fig. 1). Dune fields are mostly situated at the areas of Sunny Beach resort and the town of Nessebar [6]. In the near past, the large sandy strip of Sunny Beach resort was distinguished with a typical dune landscape related to the dominant NE and N winds. However, large parts of dunes were destroyed during the resort/hotel developments. Before human influence there were sand dunes reaching a height of 11 m and they were mostly distributed along the middle and south part of the beach. At present, despite the protection status of the coastal area in the resort, many dune fields have been levelled and overbuilt and thus the active dune areas have dramatically decreased. North of the Nessebar Peninsula a longer, but with smaller area, dune complex is located. Constant buildings of hotels and other tourist infrastructures in the Sunny Beach resort could be considered as main reasons for degradation of wide dune areas. South of the Nessebar Peninsula a larger by area dune complex (over 1 km²) is distributed and it is also under continuous disruption due to the increased growth of the Nessebar town to the west.

In south direction, the coastal section between Sozopol Bay and Veleka River mouth is characterized with a set of various sandy beaches, beach-dune systems and larger stabilized dune fields landward (Fig. 1). There are numer-

ous sand dunes at the south Bulgarian coast which are smaller by length and area than the northern ones. Dunes are formed in the lagoon and firth sections between erosion forelands. Their wide development here is a result of sand accumulation under the prevailing winds and sufficient sediment supply as these are the cases of the lagoons of Alepu and Arkutino, and the firth of Ropotamo River. In this coastal section sand dunes are distributed at many sites, for example the main locations are: along the Sozopol Bay, camping Kavatsite, the lagoons of Alepu, Arkutino and Stomoplo, and at the coastal sections south from the town of Primorsko – Kiten (Diavolski zaliv), at c. Konnik, Karaagach inlet, camping Yug, c. Emberler, camping Oasis, camping Arapya, camping Nestinarka and at the spit of Veleka River in the southernmost direction (Fig. 1). Sandy dunes at the lagoons of Alepu (Fig. 4), Arkutino and Stomoplo are well developed and preserved ones, as the dune complex at the Arkutino lagoon has the largest area of 0.7 km² and maximum height up to 50.0 m. The beaches in this section are composed of middle-size sand with prevailing quartz component, as the adjacent dunes consist of similar in composition, but finest sand [6, 11]. The dunes here are east oriented, since they reflect the direction of dominant E winds rising during the winter. North from the town of Primorsko, at the area between the lagoon Stomoplo and a sandy beach, one of the best preserved sand dune complexes along the Bulgarian Black Sea coast is located (Fig. 5). This site distinguishes with a variety of species (in particular psammophytic plants) and has a status of protected reserve.

6. Current problems related to the increasing human impacts. Despite most of the sand dunes in Bulgaria are protected areas because of their high conservational value as unique habitats, they have been exposed to the expanded anthropogenic pressure over the last decade. Coastal dunes are presently popular sites for uncontrolled hotel buildings and other intensive recreational uses, but they are also a subject of illegal sand extractions. Like other coastal regions the Bulgarian Black Sea coast has also experienced during recent years a real-estate boom and extended impacts of new developments, such as hotels and second homes emplaced too close to the shoreline or directly on the sandy dunes [13, 14]. In addition, as a consequence of many defence engineering activities along the coast and arising sediment deficit, the capacity for natural recovery of sand dunes has been severely decreased and they are now threatened by degradation.

According to the Black Sea Coast Development Act (enforced January 1, 2008) the sandy beaches and coastal dunes are protected territories, they are also included in the EU Directive 92/43 on the conservation of natural habitats [15] and in the project *Preparation of the Bulgarian Nature 2000 Network of Protected Zones*. This project was developed in accordance with priority activities of the National Action Plan for Biodiversity Conservation [16]. Despite a number of initiatives towards sand dune legislation and law regulations of

their proper use, yet there is a need of well developed management and monitoring measures for dune preservation. There is no interaction between coastal scientists, planners and decision-makers, and most of the projects have been authorized without environmental impact assessment and appropriate scientific consultations. At most recreational sites there were wide coastal dunes, which have been destroyed because of the tourist constructions, at the most famous Bulgarian resorts of Golden sands and Sunny beach. As a result, major dune areas along the Bulgarian coast were completely urbanized by hotels and other infrastructures thus disrupting large sand dune systems. Critical attention should also be paid to the conservation of the largest dune complex in the region of Kamchia River – Shkorpilovtsi beach, Nessebar town – Sunny Beach, Arkutino lagoon and the town of Primorsko. Thereafter, proper management and preservation activities should further require an accurate understanding of dune properties/behaviour, assessment of forcing anthropogenic factors that affect dune sustainability and identification of the coastal areas most vulnerable to risk of destruction.

7. Conclusions. In the recent past sand dune formations were widely distributed along the Bulgarian Black Sea coast. However, due to increased human activities the total dune landscape is constantly diminishing and dunes presently comprise only 10% of the entire coastline: the total sand dunes length is 38.57 km and the total area is 8.78 km². On the base of produced GIS-based indicative map about 20 locations with well developed beach-foredune systems, inlet dunes and more stabilized inland sand dunes were identified around the Bulgarian Black Sea coast. Large dune fields were identified at the northern part of the coast, also at the middle part and a number of smaller dune complexes were indicated along the southern Bulgarian coastline. A few of the larger dunes are located between the capes of Durankulak, Krapets and Shabla, around the large firth area of Kamchia River mouth, and near the town of Nessebar, the lagoons of Alepu, Arkutino and Stomoplo. Sand dunes at the north Bulgarian coast are more sparsely shaped, conversely they embrace more extensive coastal areas by comparison with the ones along the southern coast. Dunes at the south part are numerous and formed in the inlets between small rocky capes and lagoons. Such peculiarity in dune distribution is mainly determined by various geographical settings of the Bulgarian coast: dominant wind action, coastline orientation and configuration due to different crenulation ratio. The north coast is open and low crenulated, therefore the developed dunes embrace wide-ranging areas, while the strongly crenulated and bay-shaped south coastline has contributed to the formation of numerous smaller inlet dune systems. Between the mouths of Kamchia and Fandakliyska Rivers the largest dune complex at the Bulgarian coast is located with a length of 7180 m and area reaching up to 2 km² and these dunes are one of the priority habitats for conservation.

Although sand dunes in Bulgaria are protected areas and national reserves they have been exposed to the expanded anthropogenic pressure over the last decade. There is an increased demand of proper management and urgent conservation activities. Such measures first require an accurate understanding of dune properties/behaviour, assessment of anthropogenic factors affecting dune persistence and identification of coastal areas most sensitive to risk of destruction.

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