INITIAL ASSESSMENT OF THE TECHNOGENIC PRESSURE IN THE MEDIOLITTORAL ZONE OF THE BULGARIAN BLACK SEA COAST

Bogdan Prodanov[1]
Iliyan Kotsev[1]
Assoc. prof. Dr. Stoyan Keremedchiev[1]
Assoc. prof. Dr. Valentina Todorova[1]
Assoc. prof. Dr. Lyubomir Dimitrov[1]
[1] Institute of Oceanology "Fridtjof Nansen" – Bulgarian Academy of Sciences, **Varna, Bulgaria**

ABSTRACT. *The study presents a quantitative evaluation of the Bulgarian mediolittoral zone's physical alterations due to construction of hydrotechnical structures. It was performed in fulfillment of the obligations under the Marine Strategy Framework Directive (MSFD) to estimate the Sea-floor integrity (Descriptor 6), Physical loss and Physical damage (Descriptors 6.1 and 6.2) as part of the initial assessment of the marine environmental status. The initial assessment is based on sufficient data with low degree of extrapolation. The dense concentration of artificial structures along the Bulgarian Black Sea coast represents the main factor causing physical loss and damage of the mediolittoral substrates and habitats due to the alterations of the hydrodynamic and sediment transport regimes, manifested in deterioration of the water circulation and increased sedimentation. The varied degree of technogenic transformation within the mediolittoral zone required its division into five regions for better spatial analysis. Highest rates of technogenic pressure were identified for coastal zone sectors cape Kaliakra-cape Galata and cape Emine-cape Sozopol, while lowest were reported for cape Sivriburun-cape Kaliakra and cape Sozopol-river Rezovska. These trends are expected to continue due to forthcoming economic activities, e.g. construction of new coastal protection structures, harbor and tourist infrastructure, the completion of the "South Stream" gas pipeline etc.*

Keywords: *MSFD, marine environmental status, ICZM, coastal anthropogenic transformations, mediolittoral lithology*

INTRODUCTION

The dense concentration of hydrotechnical structures in the mediolittoral zone is among the most detrimental types of anthropogenic pressure along the Bulgarian Black Sea coast [1]. Previous studies upon related issues of the Bulgarian Black Sea coastal zone are performed by Dachev and Genov [2], Keremedchiev et al. [3], Peychev and Stancheva [4], Stancheva [5; 6], Stancheva and Marinski [7], Stanica et al. [8] etc. Authors unanimously recognize these man-made structures as the main factor causing physical damage and subsequent loss of seabed substrates and benthic habitats due to the accompanying negative effects, e.g. alterations of the hydrodynamic and sediment transport regimes, deterioration of the natural water circulation, smothering due to increased siltation etc.

STUDY AREA

Spatial extent of the Bulgarian Black Sea mediolittoral zone. Being a micro-tidal basin, the mediolittoral of the Black Sea coincides with the surf zone [1], demarcated by the wave-breaking zone from the marine side and the swash zone from the terrestrial side. In addition, some authors, e.g. Mokyevski [9], Zaytsev [10] etc. consider the mediolittoral of the micro-tidal and tideless seas to be of a specific type, which they term as ***pseudolittoral.***

Due to the regional peculiarities of several natural factors (e.g. coastal lithology, topography, bathymetry, hydrodynamics, etc.) and the anthropogenic transformations, the mean width of the Bulgarian Black Sea mediolittoral zone varies greatly in latitudinal direction, therefore its proper spatial analysis dictates the necessity of its division into five study sectors (Table 1).

Table 1: Main geometric properties of the investigated mediolittoral sectors of the Bulgarian Black Sea coast:

Study region	Width (in m) of the terrestrial part (rocky mediolittoral)	Width (in m) of the terrestrial part (sandy mediolittoral)	Area (in km²) of the terrestrial part (rocky + sandy mediolittoral)	Width (in m) of the marine part (rocky mediolittoral)	Width (in m) of the marine part (sandy mediolittoral)	Area (in km²) of the marine part (rocky + sandy mediolittoral)
c. Sivriburun – c. Kaliakra	3.0	12.5	0.022 + 0.221 = 0.243	68.0	206	2.140 + 3.632 = 5.772
c. Kaliakra – c. Galata	3.0	9.8	0.127 + 0.231 = 0.358	96.0	185	3.391 + 4.030 = 7.421
c. Galata – c. Emine	5.7	8.8	0.078 + 0.378 = 0.456	123.0	152	1.684 + 6.415 = 8.099
c. Emine – c. Sozopol	6.3	9.4	0.332 + 0.528 = 0.860	210.0	155	11.032 + 8.299 = 19.331
c. Sozopol – r. Rezovska	3.5	2.6	0.202 + 0.064 = 0.266	58.9	8.3	3.447 + 2.081 = 5.528
Mean values for entire Bulgarian Black Sea coast	4.1	9.3	0.761 + 1.422 = 2.183	121.2	9.3	21.694 + 24.457 = 46.151

Types of technogenic pressure in the Bulgarian Black Sea mediolittoral zone. There are two distinctive types of anthropogenic pressure within the Bulgarian Black Sea mediolittoral zone that provoke physical loss of semi-terrestrial or benthic substrates and habitats, namely ***sealing*** and ***smothering.*** Besides, physical damage is also caused by ***siltation***, usually related to human-induced alterations of the hydrodynamic and sediment transport regimes [1; 11]. Hence, ***sealing*** refers to the loss of mediolittoral substrates and habitats due to their coverage by various permanent constructions and installations, e.g. port infrastructure, marinas, fishermen wharfs, rocky levees, seawalls, jetties, groins etc. ***Smothering*** is mainly associated with the abnormal sediment accumulation at coastal sections, where these man-made structures are present, but also with the purposeful disposal of dredged sandy materials, aimed at, for instance, the creation of new artificial beaches [1]. The process of smothering is closely related to ***siltation***, which represents an indirect damage of the mediolittoral substrates and habitats as a consequence of altered hydrodynamic and sediment transport regimes.

DATA AND METHODS

Several fine-scale data sets with various temporal resolutions were used for the purposes of the current study, e.g. orthophoto and satellite images covering the Black Sea coastal area, ESRI shape files representing the coastal and seabed lithology etc. These are described more in detail in Table 2.

All data integration, data creation and subsequent analysis procedures were carried out in Arc Map 9.3.1 and Global Mapper 13 GIS environments. These mainly involved image mosaics composition, on-screen digitizing and follow-up creation of ESRI shape files, representing the contemporary coastline, visually identified hydrotechnical structures, gained territories and artificial sand strips. In addition, certain buffering operations were also executed for delineation of the individual spatial extents of the mediolittoral zone at the five studied sectors, as well as area calculations at the affected coastal sectors. A simplified model of the performed GIS operations is shown in Figure 1.

Table 2: Main properties of the data sets used in the current study:

Data set	File type	Pixel size / scale of the initial hard-copy maps	Relevance period	Data source
Orthophoto images	raster	0.5 m	2006-2007	Bulgarian Ministry of Regional Development and Public Works
Pan-sharpened IKONOS images (Primorsko coastal area)	raster	1 m	2010	Land Info World Mapping LLC
Georeferenced images from Google Earth (Balchik-Varna coastal areas)	raster	2 m	2011-2013	Digital Globe™
Georeferenced images from Google Earth (Elenite-Ravda coastal areas)	raster	2 m	2010	Digital Globe™
Coastal and seabed lithology	vector /ESRI shape files/	1:5,000	1973-2011	Digital archive of the Institute of Oceanology "Fridtjof Nansen"- BAS, Varna, Bulgaria

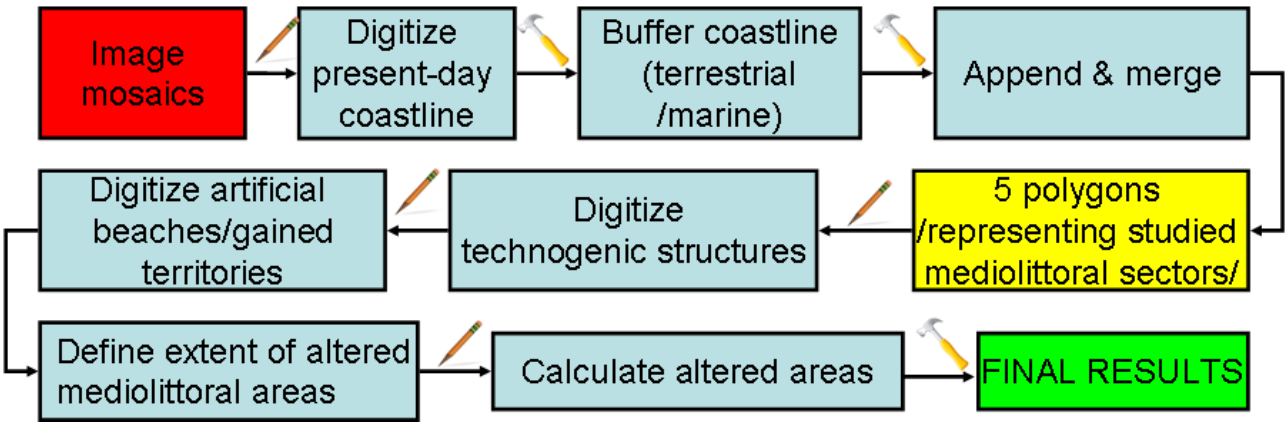

Figure 1: A simplified flowchart of the performed GIS procedures

RESULTS

Spatial distribution of the hydrotechnical structures and artificial beaches along the Bulgarian Black Sea coast. As of 2013, the hydrotechnical infrastructure established in the Bulgarian Black Sea mediolittoral zone comprises 173 entities, including 17 harbors and ports, 17 yacht marinas, 5 fishermen wharfs, 25 levees, 104 groins, jetties and breakwaters, as well as 5 seawalls. These are grouped in 84 hydrotechnical complexes, distributed rather irregularly along the shore. The greatest concentration is observed in the coastal regions cape Kaliakra-cape Galata and cape Emine-cape Sozopol. Furthermore, the performed visual image interpretations coupled with archive data analyses allowed the identification of more than thirty artificial sand strips. Again, the

majority of them are located in the cited regions, particularly at Kavarna, Balchik, Varna, Sveti Vlas, Nessebar and Ravda coastal areas.

Physical loss by sealing and smothering. As discussed above, the technogenic pressure within the Bulgarian Black Sea mediolittoral zone is rather uneven, with the greatest impacts observed at the coastal regions cape Kaliakra-cape Galata and cape Emine-cape Sozopol. The net loss of mediolittoral substrates for the entire Bulgarian sector adds up to 10.4% of the unaffected reference area [1] (Table 3).

Table 3: Relative values of technogenic pressure along the Bulgarian Black Sea coast induced by sealing and smothering:

Coastal region	Type of pressure in % of the region's mediolittoral zone		Cumulative % of physical loss (sealing + smothering)
	Sealing	Smothering	
c. Sivriburun – c. Kaliakra	0.2	0.4	0.6
c. Kaliakra – c. Galata	***20.4***	***3.0***	***23.4***
c. Galata – c. Emine	0.2	0.1	0.3
c. Emine – c. Sozopol	***13.5***	***1.4***	***14.8***
c. Sozopol – r. Rezovska	1.7	0.3	2.0
Mean relative values for the entire Bulgarian Black Sea mediolittoral zone	**9.3**	**1.0**	**10.4**

The northernmost region stretching between cape Sivriburun and cape Kaliakra is characterized by very low levels of sealing and smothering with values of 0.2% and 0.4% respectively (Table 3). The technogenic pressure within the sub-region cape Sivriburun-cape Shabla consists of rocky levees with a few jetties plus a seawall aimed at wave-induced coastal erosion attenuation. The anthropogenic structures at the second sub-region between cape Shabla and cape Kaliakra include a few quays located at "Roussalka" recreational area and Bolata Bay near the village of Bulgarevo.

Further south, the coastal region cape Kaliakra-cape Galata is characterized by the highest levels of technogenic pressure along the mediolittoral zone (Table 3), reaching as much as 37.07% for Varna coastal area that stretches between cape Ekrene and cape Galata. The anthropogenic transformations here consist of artificial sealing of the erosive-landslide sectors with levees and seawalls, while the underwater coastal slope is additionally fortified with reinforced concrete tetrapods and boulder enrockments, affecting 17.5% of the region's mediolittoral area. The total gained territory through smothering adds up to 2.6% for the shallow marine areas demarcated by the 5 m bathymetric contour, reaching up 4.2% at Varna coastal area. There is a prevalence of the natural beach-forming processes, while artificial nourishment achieved through disposal of dredged materials encompasses 0.9% of the region's sand strips (Figure 2).

The third study region stretching between capes Galata and Emine is the least affected mediolittoral sector along the Bulgarian Black Sea coast by means of artificial burial and smothering (Table 3), with almost complete absence of technogenic structures between the capes Galata and Cherni nos. The newest beach located next to Byala harbor is of semi-anthropogenic origin, whose formation is due to natural nourishment coupled with artificial disposal of sandy materials dredged from the port's area.

The region between cape Emine and cape Sozopol is the second most affected by sealing and smothering along the Bulgarian Black Sea mediolittoral zone (Table 3). The studied sector is

characterized by rather intense dynamics of coastline changes, which come as a consequence of the unprecedented sprawl of the real estate development and tourism [6], particularly valid for the sub-regions "Elenite" resort-Pomorie and Chernomorets-Sozopol.

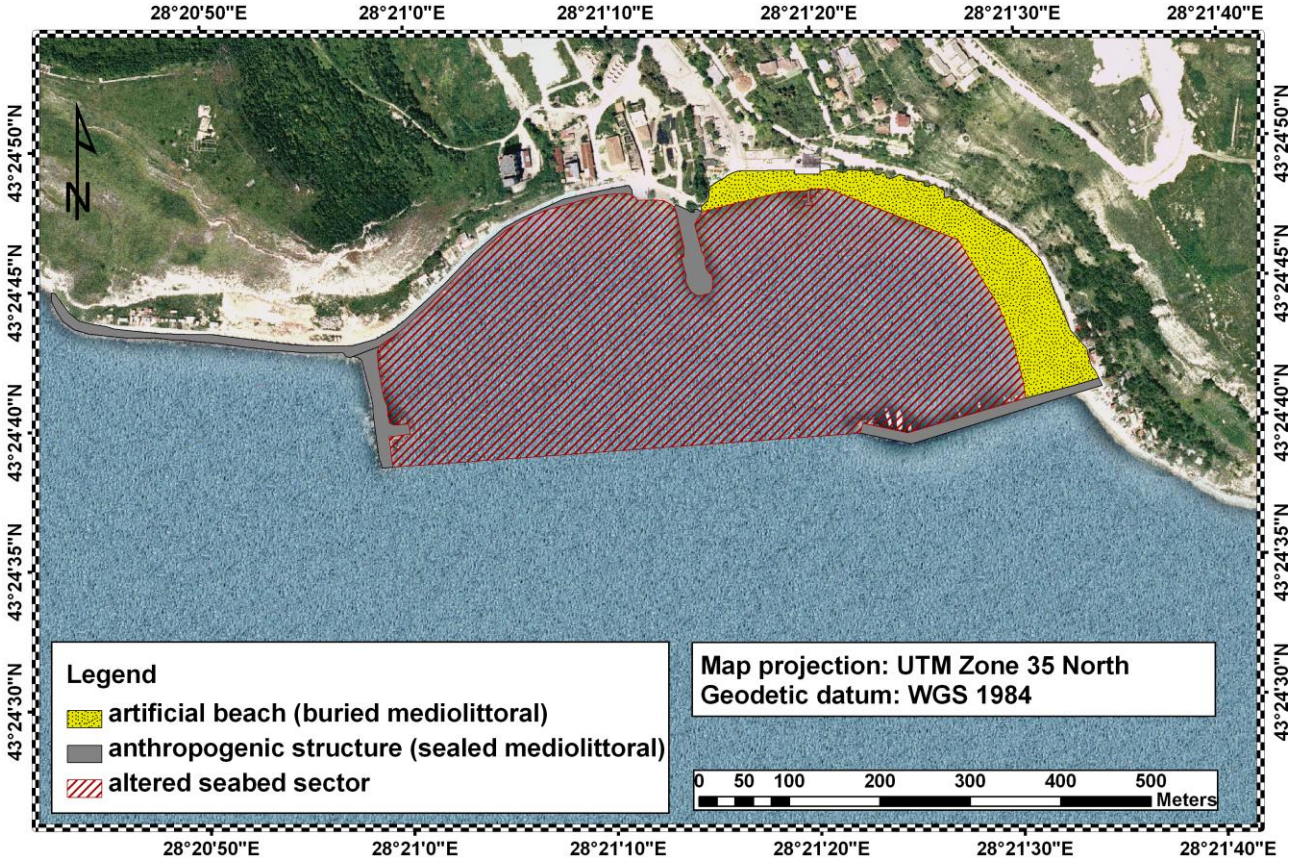

Figure 2: Physical loss of mediolittoral areas through sealing and smothering (burial). An example from Kavarna harbor

The southernmost study region cape Sozopol-river Rezovska is the third most affected by hydrotechnical structures in the Bulgarian Black Sea coastal zone. This is due to the latest development of the tourist, transport and coastal protection infrastructure near "Dyuni" recreational area, Primorsko, Kiten, Tsarevo, Ahtopol etc. Nevertheless, the rates of human-induced mediolittoral alterations are considerably lower in comparison to the contiguous region cape Emine-cape Sozopol, with cumulative percentage of physical loss barely reaching 2% (Table 3). The total gained territory through creation of artificial sand strips is insignificant.

The performed initial assessment with reference to the physical loss of mediolittoral substrates through sealing and smothering demonstrates highest values for coastal regions cape Kaliakra-cape Galata, cape Emine-cape Sozopol and, to a certain extent, cape Sozopol-river Rezovska (Table 4). The percentages of physical loss of mediolittoral sediments through sealing and smothering are 47.5% and 8.5% respectively for region cape Kaliakra-cape Galata. These relative values reach 30.8% and 3.2% respectively for the coastal zone stretching between the capes Emine and Sozopol. The affected percentages of the mediolittoral rocks through sealing and smothering are 31.6% and 4.6% respectively for the region cape Kaliakra-cape Galata, while these for the region cape Emine-cape Sozopol are 23.9% and 2.4% respectively. The same indicators of the technogenic pressure

reach relative values of 4.2% and 6.3% for the southernmost coastal region between cape Sozopol and river Rezovska.

Table 4: Relative values of physical loss of mediolittoral sediments through sealing and smothering estimated for the five study sectors of the Bulgarian Black Sea coastal zone:

Type of physical pressure by coastal region	Affected % of the region's all mediolittoral sediments	Affected % of the region's all mediolittoral rocks
c. Sivriburun – c. Kaliakra		
Sealing	0.3	0.1
Smothering	0.6	1.1
c. Kaliakra – c. Galata		
Sealing	***47.5***	***31.6***
Smothering	***8.5***	***4.6***
c. Galata – c. Emine		
Sealing	0.3	1.2
Smothering	0.1	0.5
c. Emine – c. Sozopol		
Sealing	***30.8***	***23.9***
Smothering	***3.2***	***2.4***
c. Sozopol – r. Rezovska		
Sealing	7.1	4.2
Smothering	1.1	***6.3***

Physical damage by changes in siltation rates. Besides the direct physical loss of mediolittoral sediments and habitats, the construction of hydrotechnical infrastructure in the coastal zone causes also indirect damage, usually manifested in deterioration of the natural hydrodynamic and sediment transport regimes, resulting in changes of the normal siltation rates (Figure 3).

The quantified results of the performed assessment demonstrate that 12.7% of the Bulgarian Black Sea mediolittoral zone is negatively affected by increased siltation of technogenic origin. Once again, the levels of impact vary greatly from one coastal sector to another. Nevertheless, two of the studied regions, namely cape Kaliakra-cape Galata and cape Emine-cape Sozopol, stand out with rather high percentage of deteriorated mediolittoral environment due to changes in siltation (Table 5).

Table 5: Relative values of physical damage of the mediolittoral zone induced by increased siltation of technogenic origin:

Coastal region	Physical damage by increased siltation in % of the region's mediolittoral zone
c. Sivriburun – c. Kaliakra	0.4
c. Kaliakra – c. Galata	***19.0***
c. Galata – c. Emine	0.5
c. Emine – c. Sozopol	***23.1***
c. Sozopol – r. Rezovska	2.1
Mean relative values for the entire Bulgarian Black Sea mediolittoral zone	**12.7**

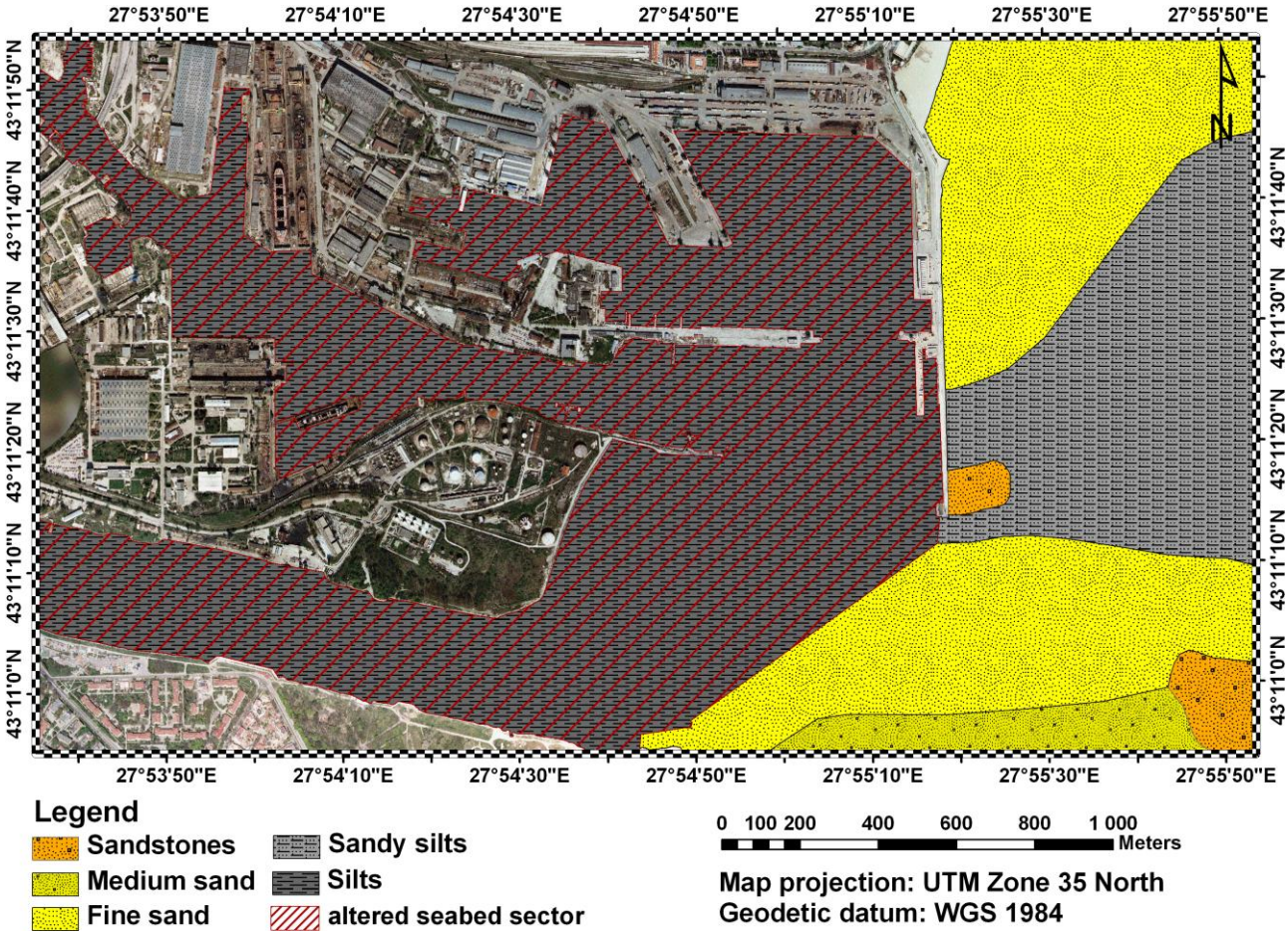

Figure 3: Physical damage of a seabed sector through technogenically-induced siltation. An example from Port Varna-East

The northernmost study region stretching between cape Sivriburun and cape Kaliakra is characterized by prevailing east and east-northeast coastal expositions, which are open to wave action coming from the northeast, east and southeast quarters. Hence, the entries of the coastal marine areas sheltered by multipurpose hydrotechnical infrastructure remain at the lee side of the wave direction. These peculiarities of the wave climate at the investigated mediolittoral region create conditions for deteriorated natural hydrodynamic and sediment transport regimes, resulting in conversion of the seabed from a hard-bottom into a soft-bottom environment, with various ecological implications for the associated benthic habitats. Nevertheless, the affected portion of the mediolittoral zone here is just 0.4%, making it the least impacted along the Bulgarian Black Sea coast (Table 5).

The aggregate altered mediolittoral area between cape Kaliakra and cape Galata adds up to 19% of the studied region, making it the second most impacted along the Bulgarian Black Sea coast. These values reach as much as 32.63% for Varna coastal area. This is mainly due to the orientation of the pier entries, the L- and Y-shaped groins, facilitating the accumulation of sandy and silty sediments at their lee sides (Table 5).

The third coastal region stretching between cape Galata and cape Emine is characterized by low percentage of the affected mediolittoral (0.5%), with the sub-region cape Galata-cape Cherni nos being almost free of any technogenic pressure (Table 5).

Further south, the region stretching between cape Emine and cape Sozopol is the most impacted by siltation along the Bulgarian Black Sea coast, with 23.1% of its littoral zone being affected. The coastal exposition varies from north-northwest to southwest. The orientation of the coastal protection structures and the entries of the yacht marinas and harbor docks remain at the lee side of the wave activity, which creates conditions for deterioration of the hydrodynamic and sediment transport regimes (Table 5).

The contiguous investigated sector stretching between cape Sozopol and river Rezovska has similar coastal orientation regarding the wave climate and similar siltation issues associated with the erroneous position of the hydrotechnical structures. Nevertheless, thanks to the relatively scarce presence of such infrastructure, only 2.1% of the studied region's mediolittoral zone is affected by changes in siltation (Table 5).

The results of the performed initial assessment concerning the relative areas of the mediolittoral substrates affected by changes in the siltation rates are provided in Table 6. The data clearly indicate that the coastal regions cape Kaliakra-cape Galata and cape Emine-cape Sozopol are the most affected by changes in siltation due to the excessive concentration of hydrotechnical structures at these shore sectors.

Table 6: Relative values of mediolittoral sediments affected by siltation along the Bulgarian Black Sea coast:

Coastal region	% of mediolittoral sediments affected by increased siltation	% of mediolittoral rocks affected by increased siltation
c. Sivriburun – c. Kaliakra	0.61	1.09
c. Kaliakra – c. Galata	***43.8***	***29.39***
c. Galata – c. Emine	0.81	3.10
c. Emine – c. Sozopol	***54.37***	***42.23***
c. Sozopol – r. Rezovska	**8.47**	**4.98**
Mean relative values for the entire Bulgarian Black Sea mediolittoral zone	**10.2**	**7.5**

DISCUSSION AND CONCLUSIONS

The performed GIS-based analyses reveal that the major maritime hydrotechnical structures are grouped in 84 large complexes, distributed rather irregularly along the Bulgarian Black Sea coastal zone. As a consequence, the degree of technogenic pressure exerted upon the mediolittoral zone varies greatly in latitudinal direction, which requires its division and further investigation as five study regions for optimization of the spatial analysis.

Overall, 10.4% of the Bulgarian mediolittoral zone is transformed through sealing and smothering of anthropogenic origin, which is closely related to the erroneous excessive concentration of harbor, coastal protection and tourist infrastructure there. Additional 12.7% are indirectly affected because of the altered hydrodynamic and sediment transport regimes, manifested through intensified siltation rates near these large maritime hydrotechnical complexes. As the present research demonstrates, strongest smothering and siltation impacts are registered for the mediolittoral sandy sediments, making the associated semi-terrestrial and benthic habitats the most vulnerable along the Bulgarian Black Sea coastal zone.

The highest estimates of physical loss and physical damage obtained for two of the investigated regions, namely cape Kaliakra-cape Galata and cape Emine-cape Sozopol, are with serious implications for the state of the mediolittoral environment there. The registered negative trends at these coastal sectors are expected to continue due to forthcoming economic activities, incorporating the construction of new coastal defense, harbor and tourist infrastructure, the completion of the "South Stream" gas pipeline etc.

The existing land use practices and real estate investment initiatives along the Bulgarian Black Sea coast seldom take into consideration the conservation of the characteristic mediolittoral landscapes and the habitats. Thus, the social and economic goals of the coastal structures development often involve high environmental cost and degradation. Hence, proper marine spatial planning and science-based integrated coastal zone management along the Bulgarian Black Sea coast have a strong implication for the maintenance of good environmental state of the coastal marine waters, habitat loss considered an irreversible threshold that shall not be crossed.

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REFERENCES

[1] Todorova V., Panayotova, M., Prodanov, B., Keremedchiev, S., Kotsev, I. Physical loss and physical damage. In: Todorova, V., S. Moncheva (Eds.) Initial assessment of the current state of the marine environment in accordance with RPEMW, 2013, pp. 253-259 *(in Bulgarian)* (available at www.bsbd.org) (Last accessed: November 29th, 2013)

[2] Dachev, V.,Genov, R. Maritime construction and accompanying effects along the Bulgarian Black Sea coast. *Proceedings of the Institute of Oceanology-BAS*, vol. 2, 1998, pp. 120-126 (in Bulgarian) (available at www.io-bas.bg) (Last accessed: November 29th, 2013)

[3] Keremedchiev, St., Trifonova, E., Valchev, N., Andreeva, N., Eftimova, P., Demireva, D. PLANCOAST – spatial planning of Varna coastal area between cape Ekrene and cape Paletsa. Final project report, 2007. *Scientific fund of the Institute of Oceanology "Fridtjof Nansen", Varna – Bulgarian Academy of Sciences (in Bulgarian)*

[4] Peychev, V., Stancheva, M. Changes of sediment balance at the Bulgarian Black Sea coastal zone influenced by anthropogenic impacts. *Comptes rendus de l'Academie bulgare des Sciences*, Vol. 62, issue 2, 2009, pp. 277-284

[5] Stancheva, M. Indicative GIS-based segmentation of the Bulgarian Black Sea coastline for risk assessment. *Comptes rendus de l'Academie bulgare des Sciences*, Vol. 62, issue 10, 2009, pp. 1311-1318

[6] Stancheva, M. Human-induced impacts along the coastal zone of Bulgaria. A pressure boom versus environment. *Comptes rendus de l'Academie bulgare des Sciences*, Vol. 63, issue 1, 2010, pp. 137-146

[7] Stancheva, M., Marinski, J. Coastal defense activities along the Bulgarian Black Sea coast – methods for protection or degradation? *Proceedings of the 5th International Conference Coastal structures*, Venice, Italy, 2-4 July 2007, pp. 480-489

[8] Stanica, A., Stancheva, M., Ungureanu, G., Peychev, V., Palazov, A., Stanchev, H., Dutu. F. Types and Impacts of Maritime Hydraulic Structures on the Romanian - Bulgarian Black Sea Coast - Setting-up a Common Catalogue for GIS-based Coastline Classification. *Geo-Eco-Marina Journal*, vol. 18, 2012 (available at www.geoecomar.ro/website/publicatii-revista-geo-eco-marina.html) (Last accessed: November 29th, 2013)

[9] Mokyevski, O. B. Geographical zonation of marine littoral types. *Limnology and Oceanography*, Vol. 5, issue 3, 1960, pp. 389-396

[10] Zaytsev, Yu. Chapter 8.3. Observations of flora and fauna of sandy beaches. In: *An introduction to the Black Sea ecology*, 2001, pp. 134 (available at www.dtic.mil/get-tr-doc/pdf?AD=ADA469412) (Last accessed: November 29th, 2013)

[11] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)