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(RESEARCH ARTICLE)

Vulnerability assessment of coastal plant communities from flooding caused by unusual storms: A case study of Kabakum beach, Varna (Northeastern Bulgaria) for 2018 year

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Abstract

The present paper proposed a rapid method for vulnerability assessment of coastal plant communities from flooding caused by unusual storms over the Bulgarian Black Sea Coast. The model was tested and applied on Kabakum beach, Varna (Northeastern Bulgaria) for 2018 year. In order to create a dynamic GIS model, data from experimental results and detailed GIS mapping on the Kabakum beach (Varna) were incorporated. As a result of a simulated flooding experiment, Critical Decomposition Time (CDT) was obtained. Linking flood duration with CDT and altitudinal spreading of plants determines that *Artemisia vulgaris* L., *Eryngium maritimum* L. and *Crambe maritima* L. are vulnerable to storms. The plant communities in Kabakum beach are not threatened by complete destruction even during a storm with a return period of 100 years. Habitat recovery is likely within a season and does not require human intervention.

Keywords: Vulnerability assessment; Plant communities; GIS; Floods; The Black Sea coast

1. Introduction

Coastal areas are very fragile ecosystems that are sensitive to global climate changes, sea level rise and frequent storm surges [1-3]. These areas, with their naturally established coastal dunes, perform important ecosystem services such as protection against storm waves, storm surges, and high tides [3, 4], and act as a buffer for low-lying inland urbanized and agricultural territories [5, 6]. They provide habitats for many rare and endangered species, which will be lost due to the combination of negative consequences of flooding and erosion as well as strengthen anthropogenic impact [3, 6, 7].

Varna city coastal area (Northeastern Bulgaria) is relatively protected from sea floods. The main reasons for this are the small amplitude tides in the Black Sea and the lack of big rivers flowing into the Varna Bay [7, 8, 9]. The only risk comes from extreme meteorological events such as unusual storm surge levels in combination with reinforced wave upon the shore [7, 10, 11]. Recorded damages from storms over the Bulgarian Black Sea Coast [7, 8, 9] showed the negative impact to the dunes and the high potential of the root systems of some of the native psammophytes to accumulate sand and prevent from washout [3, 9-11].

Although the coastal plant communities are well adapted to salt stress due to their regular exposure to sea water, some of the species are vulnerable and sensitive to the impact of flooding [12, 13]. Plants could be affected by direct storm-wave damages during which they are uprooted or buried by sediments [1]. These factors in combination with increasing human impact may lead to various negative consequences to coastal plant communities in the long term [7].

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The necessity to assess and to quantify these negative effects on natural habitats requires the development of rapid models for vulnerability assessment. Different flood scenarios and models were introduced in order to assess possible negative consequences to coastal areas from storms [7, 10, 11]. However, more of them are focused only to socio-economic dimensions [e. g. 14].

This paper proposes a rapid method for vulnerability assessment of coastal plant communities from flooding caused by unusual storms over the Bulgarian Black Sea Coast. The model was verified by practical application of experimental data on Kabakum beach, Varna (Northeastern Bulgaria) for 2018 year.

2. Material and methods

2.1. Simulated flooding experiment

Thirty whole plants from each investigated species were eradicated at Kabakum Beach, Varna (43°18′20.92′′N, 28°03′13.51′′E) in April 2018 and were planted in washed and sterilized sand taken from their natural habitats in 10 × 10 × 17 cm^3 plastic pots. After a month of acclimatization in the Biological Laboratory of the Technical University of Varna, the plants with pots, separated in three equal groups, were completely submerged in three 100 l glass tanks full of sea water (18‰ salinity) with maintained constant temperatures of 4±1, 13±1, and 23±1 °C, respectively, for 480 hours. The water was changed twice a day in order to avoid water putrefactive processes [3, 6, 9].

Visible morphological changes of different parts of the plants (leaves, stems, roots) and the effect of flooding on the viability of the studied specimens were recorded and assessed in 12 parameters (see Table 1). The beginning of decomposition of different parts was set to a time point when visible changes of decay were more than 15% of the whole vegetative organ surface. Complete decomposition was when the visible decomposition of an organ exceeded 50% of its surface [12].

The temporal expression of plant species survival can be presented as a critical decomposition time (CDT) by linking the duration of flooding and resilience of plant species. CDT is a parameter that is subjectively defined on visible morphological changes and represents the smallest degree of irreversible decay of vegetative organs (more than 15% of the whole vegetative organ surface), and it indicates that the plants will not survive flooding with longer duration and their communities will not be able to recover [3, 6, 7, 12].

2.2. Intensity Duration Frequency (IDF) vs. altitudinal spreading

Various datasets and models were used in order to estimate the possible negative consequences of flooding to plant communities. To implement hydrodynamical modelling, detailed topography and bathymetry surveys were carried out and 2 typical cross-shore profiles were constructed along Kabakum Beach. The topography surveys were accompanied by detailed GIS mapping of the plant communities. Flood duration was calculated for four return periods (RP) - 5, 20, 50 and 100 years. IDF (Intensity Duration Frequency) functions were constructed for each representative cross-shore profile [7].

3. Results and discussion

A flowchart of the rapid method for vulnerability assessment of coastal plant communities from flooding caused by unusual storms over the Bulgarian Black Sea Coast is presented in Figure 1. The model allows experimental results to be applied directly to the present situation and to predict the effects of future storm events on the dune vegetation.

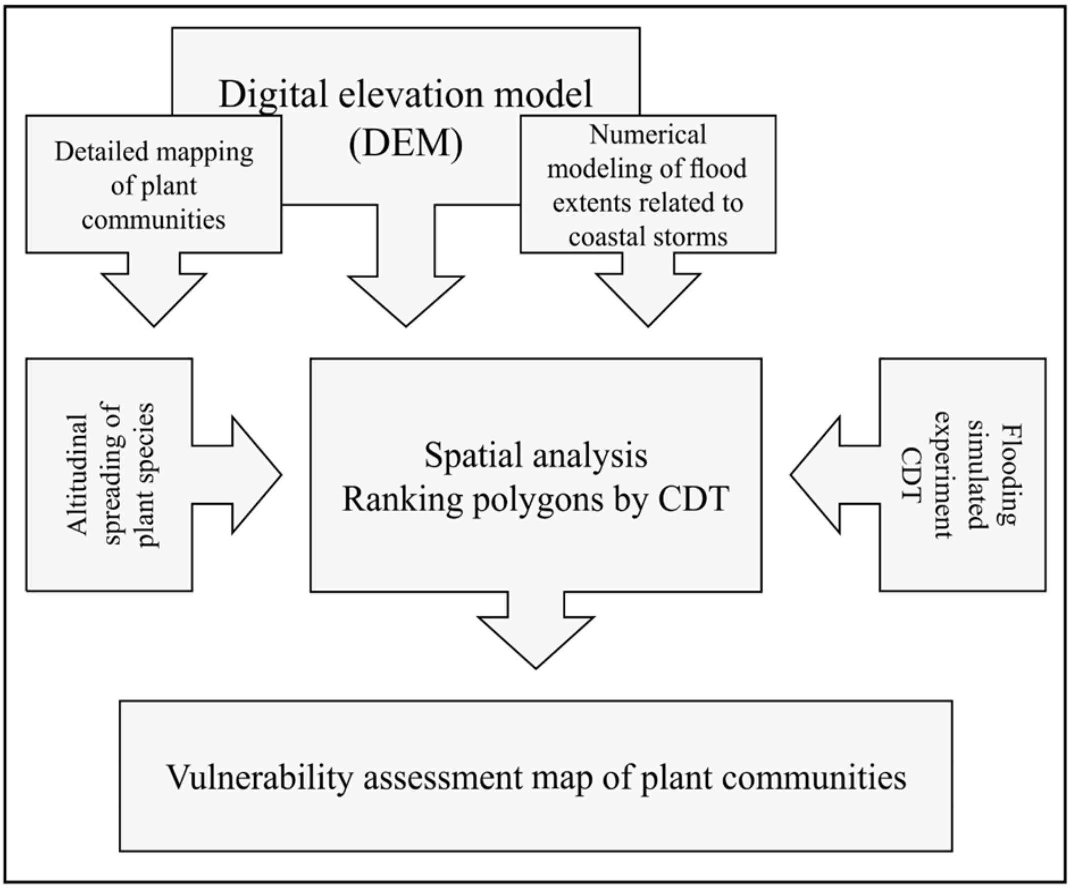

Figure 1 Flowchart of rapid method for vulnerability assessment of coastal plant communities to flooding caused by unusual storms over the Bulgarian Black Sea Coast

Different flood patterns were explored by means of morphodynamical modeling [7]. Forcing relevant for present climate conditions was obtained using statistical analysis of surge data and numerical modeling of wave action. The interpretation of the results links flooding duration and elevation above the mean sea level due to surge events for four return periods: 5, 20, 50, and 100 years [7]. Flood durations from a number of scenarios were ranked by flood elevation in order to produce intensity-duration-frequency (IDF) curves [11, 12].

A full inventory of vascular plants was conducted in the investigated area between May and October 2018 year. Overall 14 plant species were recorded and mapped but according to flood maps [7] only 8 of them are threatened by flooding: *Crambe maritima* L., *Artemisia vulgaris* L., *Eryngium maritimum* L., *Salsola ruthenica* Iljin, *Xanthium strumarium* L., *Cynodon dactylon* (L.) Pers., *Leymus racemosus* subsp. *sabulosus* (M. Bieb.) Tzvelev, and *Ammophila arenaria* (L.) Link.

The proposed model was based on the experimental methods of simulating sea water floods without taking into consideration the direct mechanical effects of storm waves. Previous studies [3, 7, 9] demonstrated that experimental methods of direct submergence were more appropriate than the experiments of studying substrate salinity and salt spray due to regular exposure of dune plants to sea water and specific mechanisms of neutralizing sea water salt [3].

As a result of the test Critical Decomposition Time (CDT) was obtained (Table 1).

Although the storm events at the Black Sea Coast occur during winter and early spring, when average surface sea water temperature is about 4ºC [15], two other treatments with temperatures of 13ºC (average surface sea water temperature) and 23ºC (average summer surface sea water temperature) were included in the simulated experiment in order to study the relation between temperature and CDT [3]. Most of the investigated parameters were unrelated to water temperature except those concerning leaves decay of *C. maritima*, *E. maritimum* and *X. strumarium*.

Table 1 Results from simulated flooding experiment. Data in bold are accepted as CDT.

Plant	T ºC	Parameters											
		Beginning of decomposition of			Complete decomposition of			Growth of		Beginning of decomposition of newly grown		Complete decomposition of newly grown	
		leaves	stems	roots	leaves	stems	roots	stems	roots	stems	roots	stems	roots
C. maritima	4	48	168	192	96	312	336	n/a	n/a	n/a	n/a	n/a	n/a
	13	42	168	192	96	312	336	n/a	n/a	n/a	n/a	n/a	n/a
	23	**42**	168	192	96	312	336	n/a	n/a	n/a	n/a	n/a	n/a
A. vulgaris	4	48	192	240	114	336	360	n/a	120	n/a	216	n/a	312
	13	48	192	240	114	336	360	n/a	120	n/a	216	n/a	312
	23	**48**	192	240	114	336	360	n/a	120	n/a	216	n/a	312
E. maritimum	4	48	168	192	96	312	336	n/a	n/a	n/a	n/a	n/a	n/a
	13	48	168	192	96	312	336	n/a	n/a	n/a	n/a	n/a	n/a
	23	**42**	168	192	96	312	336	n/a	n/a	n/a	n/a	n/a	n/a
S. ruthenica	4	72	264	312	216	384	408	n/a	120	n/a	384	n/a	408
	13	72	264	312	216	384	408	n/a	120	n/a	384	n/a	408
	23	**72**	264	312	216	384	408	n/a	120	n/a	384	n/a	408
X. strumarium	4	96	240	288	240	360	384	240	240	288	288	432	432
	13	96	240	288	234	360	384	240	240	288	288	432	432
	23	**88**	228	288	234	336	384	240	240	282	288	432	432
C. dactylon	4	144	264	360	408	n/a	n/a	120	144	n/a	n/a	n/a	n/a
	13	144	264	360	408	n/a	n/a	120	144	n/a	n/a	n/a	n/a
	23	**144**	264	360	402	n/a	n/a	120	144	n/a	n/a	n/a	n/a
L. racemosus subsp. *sabulosus*	4	168	n/a	n/a	480	n/a	n/a	168	168	n/a	n/a	n/a	n/a
	13	168	n/a	n/a	480	n/a	n/a	168	168	n/a	n/a	n/a	n/a
	23	**168**	n/a	n/a	480	n/a	n/a	168	168	n/a	n/a	n/a	n/a
A. arenaria	4	168	n/a	n/a	456	n/a	n/a	168	168	n/a	n/a	n/a	n/a
	13	168	n/a	n/a	456	n/a	n/a	168	168	n/a	n/a	n/a	n/a
	23	**168**	n/a	n/a	456	n/a	n/a	168	168	n/a	n/a	n/a	n/a

The integration of results from altitudinal spreading of investigated species and IDF functions, as well as linking flood duration and CDT for these species, showed that the communities of *A. vulgaris*, *E. maritimum* and *C. maritima* were vulnerable to storms in the investigated area (Fig. 2) for 2018 year.

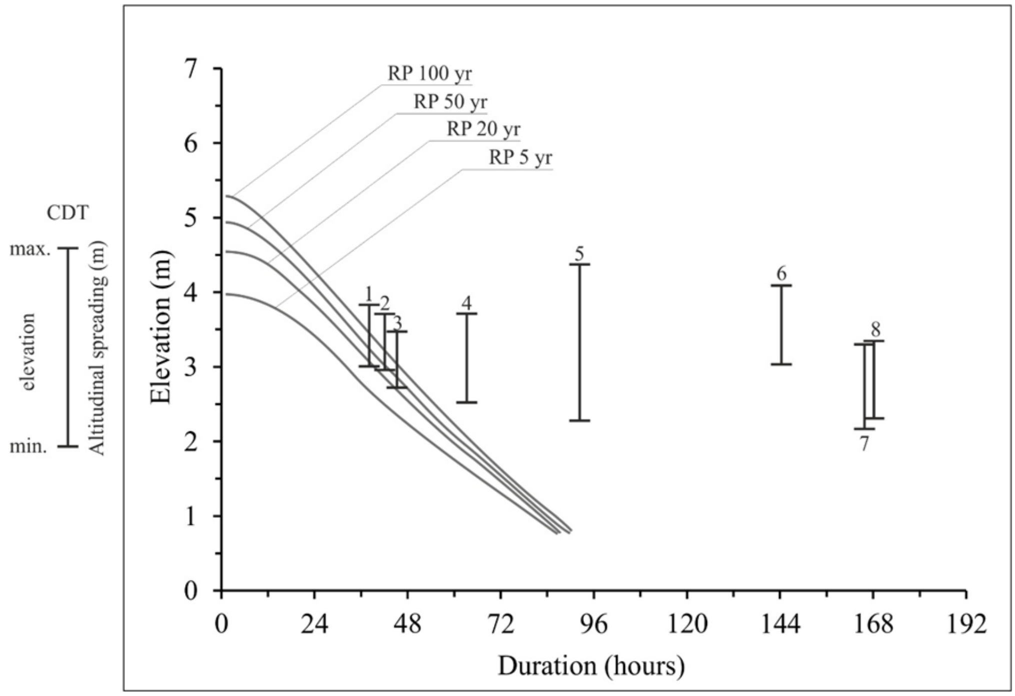

Figure 2 IDF (Intensity Duration Frequency) functions and spatial distribution vs. CDT. 1. *C. maritima*, 2. A. vulgaris, 3. *E. maritimum*, 4. *S. ruthenica*, 5. *X. strumarium*, 6. *C. dactylon*, 7. *L. racemosus* subsp. *sabulosus*, 8. *A. arenaria*

According to the experimental results, the investigated species can be divided into 3 groups: CDT < 48 h, CDT = 48 - 96 h, and CDT > 96 h.

The potentially threatened plant communities were mapped and ranked by CDT (Fig. 3) in order to produce vulnerability assessment maps. The maps in the present case study were constructed for most significant floods with greatest extents related to eastern storm events with RP 100 yrs. [7].

The plant communities in Kabakum beach are not threatened by complete destruction, even during a storm with return period of 100 years. The recovery of the habitat does not require human intervention and full recovery is likely within a season, therefore the Environmental Vulnerability Index [16] could be estimated to be equal to 1.

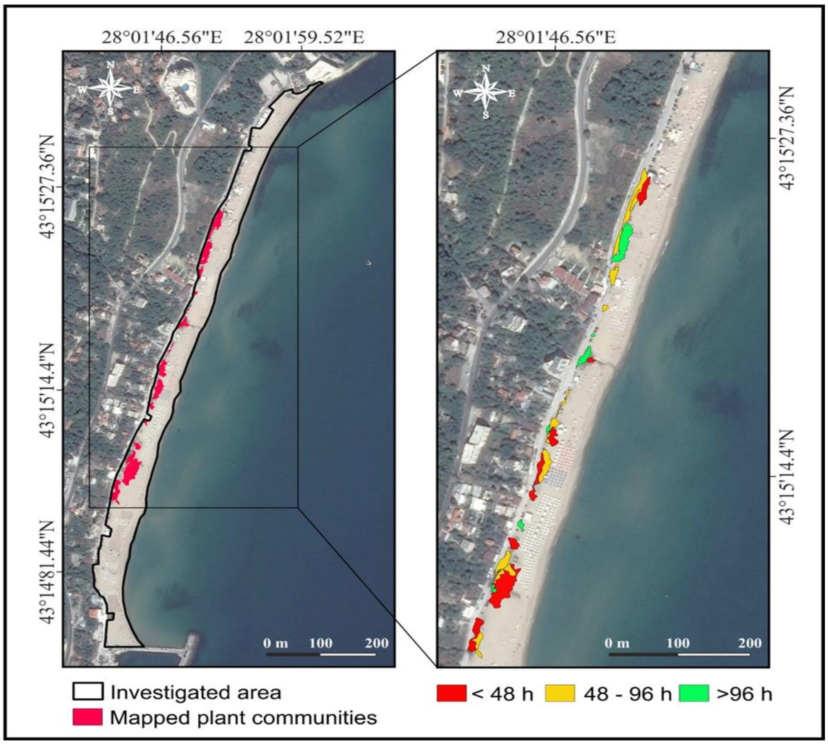

Figure 3 Map of investigated area and mapped plant communities at Kabakum beach (left) and vulnerability assessment map with ranked polygons by CDT (right) for floods with greatest extents, which are related to eastern storm events with RP 100 yrs. (Satellite images: Google Earth 2017, TerraMetrics; CNES/Airbus).

4. Conclusion

The proposed GIS-based rapid method for vulnerability assessment is applicable and has allowed the experimental results to be applied directly to a present situation to predict the effects of future storm events on the dune vegetation. The integration of the results from inventory, distribution and altitudinal spreading of plants and flooding maps for Kabakum Beach shows that only 8 species are potentially threatened by flooding during storm events. Linking flood duration and CDT for these species determines that *Artemisia vulgaris*, *Eryngium maritimum* and *Crambe maritima* are vulnerable to storms. The plant communities in Kabakum beach are not threatened by complete destruction even during a storm with a return period of 100 years. The recovery of habitat does not require human intervention and full recovery is likely within a season. Therefore, the Environmental Vulnerability Index could be estimated to be equal to 1.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare the absence of a conflict of interest.

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