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GIS models of the environmental factors and the sustainable territorial development constraints in three nature protection areas in the city of Plovdiv

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ABSTRACT

The aim of this study was to define and to analyze the environmental and territorially-determined factors and constraints influencing the sustainable development and the sustainable management of three protected areas located in the city of Plovdiv. The study sites are natural protection areas of unique nature due their mixed natural and anthropogenic functions. Being integral parts of the city they are balancing the requirements of specialized nature protection with their typical urban recreational role as urban parks. In order to meet the requirements of all these overlapping and sometimes controversial functions, the present study analyses the territorial development factors and constraints through detailed geo-informational models of the territory and its biotic, abiotic, natural and anthropogenic structures. These models were developed as part of the work on the management plans of the three protected sites. The biotic and abiotic factors were investigated through field surveys where all major plant and animal groups were studied. All important species and habitats, all specific threats and conservation problems together with all anthropogenic structures were mapped as parts of the GIS model which then served as a basis for the functional zoning of the three protected territories.

Key words: GIS modeling, protected areas management, sustainable development, environmental factors, development constraints

Introduction

The purpose of the present study was to define and to analyze the environmental, territorial and anthropogenic factors and constraints influencing the sustainable development and the sustainable management of three protected areas located in the city of Plovdiv.

The three study sites: "Bunardzhika" (also known as "Halm na osvoboditelite" hill or "Liberators' hill"), "Danov halm" ("Sahat tepe"), and "Mladezhki halm" ("Dzhendem Tepe" or "Youth Hill") are all protected under the Protected Territories Act. All three of them are designated as protected territories with the statute of natural monuments. The specific regime in the three sites requires the protection of the natural rock formations, the ecosystems and habitat diversity and the diversity of flora and fauna (Dimitrov et al., 2002), but also the park developments (green areas, monuments, water effects, etc.).

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What is unique for them as natural protected sites however is that they are located in a heavily urbanized area - the central region of Plovdiv, with two of the sites (Danov hill and Bunardzhika) - just a few hundred meters from the main streets of the city. Due to their location in the historic core of the city, among the housing and public service areas (shops, cafes, restaurants, educational facilities, etc.) the three natural monuments have developed as an irreplaceable part of the urban structure. In their role as recreational urban parks they have been integral parts of the city throughout its historical development and nowadays their landscape forms a major part of the image of the city itself. In order to meet the requirements of the overlapping and sometimes controversial functions of nature protection and urban recreation in the three study sites, the present study analyses the territorial development factors and constraints through detailed geo-informational models of the territory, its biotic, abiotic, natural and anthropogenic structures. The spatial models then served as a basis for the functional zoning and of the three protected sites as a management tool for their sustainable development.

Materials and Methods

The geo-informational models of the three protected sites are based on detailed, up-to-date data on the specific biotic and abiotic factors, the natural and the anthropogenic conditions characterizing each of the three study sites. The biotic and abiotic factors were investigated through series of field surveys where all major plant and animal groups were studied and all important species and habitats, as well as all specific major threats and conservation problems were analyzed and mapped as parts of the GIS model.

The biological surveys were organized in 6 thematic groups: Phytocoenological and habitat surveys; Ornitological surveys; Invertebrates; Terrestrial mammals; Bats; Amphibians and Reptiles. Together with the biological surveys a series of general examinations were carried out in order to analyze the abiotic environment, the condition of the social and technical infrastructure. These examinations were used to also carry out opinion polls and to analyze the visitors' profile and social needs related to the functions of the studied territories. The biotic surveys were organized according to commonly used survey methodologies specific to each of the studied biological groups. The phytocoenological surveys were carried by the Vascular plant monitoring methodology, approved by the Ministry of Environment as a rule for the National Biodiversity Monitoring System (http://goo.gl/Aaq6bp). The surveys used the approach of "instantaneous" monitoring in the period of formation of reproductive structures which allows not only to record the current presence or absence of the local populations but to gather information on the development rates and the reproduction potential of the species. The surveys gathered information also on the location (GPS data), floristic region, type of reporting unit, phoenological phase, general characteristics of the habitat area, population size, projective cover, population density, presence of invasive species, etc. (Bondev, 2002). The data was then analyzed to define the status of the plant communities, the presence of rare, endangered, endemic, relict and other valuable species and the existence of any conservational problems.

The ornithological surveys used some of the most common nesting bird monitoring methods - the line transects and point-count techniques (Bibby et al., 1992). According to the methodology the observer moves through the territory on predetermined transect routes while recording the nests and the birds identified along both sides of the transect line. The recorded number of nesting birds is then used to calculate the population density in the studied area. In hard terrains and inaccessible areas the point-counts method was used - visual and sound observations were made in stationary points within the studied site. The observations provided data on the number of birds, species composition and territorial composition of the populations. The observations required GPS devices, photo cameras and 10x50 and 8x30 binoculars.

The terrestrial mammals investigation used several survey methods depending on the ecological group studied by each of them. For the smaller mammals of orders Insectivora and Rodentia Sherman-live trapping methods were used. Together with that the surveys included additional observations based on the transect method (similar to the one described above), complemented with a questionnaire survey – interviews with people working in, visiting or living near the three studied sites.

The flying mammals (Chiroptera) were investigated in a separate group of surveys. There were three main invastigation methods used to cover the whole territory: 1) Direct observation: The method is used for temporary and/or permanent bat habitats such as buildings, rock niches, caves, etc. where the species can be determined without them being captured and the bats and/or their colonies can be photographed for further analysis; 2) Capture methods - using specialized "mist" nets with polyester monofilament fibers; and 3) Sound recording methods – using specialized ultrasound detectors in preliminary selected recording points covering the whole territory of the studied sites (Tilova et al., 2008, Stoycheva et al., 2009). The recorded data was then transformed and analyzed in a special computer software (BatSound 3.1) to define the species composition in each monitoring point.

The amphibians and the reptiles are studied visually using again line transects. The species were captured by hand, by specialized net-sack or by string trap and then released in the same location. Some of the individuals were identified by their calls or by their eggs, larvae etc. The locations were recorded with GPS coordinates.

Samples of the invertebrates were gathered through the common methods of "mowing" with a standard entomological sack (used in grassy biotopes, tree and bush branches) capturing in pitfall traps and collection by hand. The transect method was used here as well.

The data gathered and produced in the field surveys was afterwards analyzed and processed into a common geo-database together with the data received from previous surveys and from other sources such as the Municipality of Plovdiv (as a management authority of the three protected sites), by the Ministry of Environment and by a list of 15 other institutions, holding information that relates to the management of the three protected sites. This includes data from previous management plans, cadastral data, urban development plans, data from specialized registers, information systems, etc.

Incorporating all this diverse data into a common spatial data base of a single geo-informational model is a complex task as it requires the digitalization of all the information into a computerized spatial model and geo-referencing all the data in a common coordinate system. This means that all digital maps and schemes and their structural elements had to be converted in GIS usable format. Then all digitalized spatial data as well as all raster data had to be geo-referenced and unified in a single spatial model for each of the study sites. Due to the diverse nature of the input data the development of the spatial models required the usage of various software. MKAD, CADIS and Arcv2CAD were used for the visualization and the conversion of cadastre data. Some of the CAD files had to be converted initially to AutoCAD files and then to GIS files. The digitalization and the conversion of the field data required the usage of several application such as MapSource, DNR_GPS, MapInfo and GoogleEarth. As main GIS applications a combination of ArcGIS and QuantumGIS (QGIS) for Desktop were used, together with a number of coordinate transformation applications and scripts.

Results

As management tools, the GIS models of the three protected sites consist of a large number of layers, representing the geo-referenced interpretations of the environmental biotic and abiotic conditions the land-specific natural and anthropogenic factors influencing the ability and the rates of the sustainable development of the territory. All models are based on administrative framework of layers representing basic legal requirements and settings set for this particular territory which then forms an integral part and a basis for each of the spatial models.

Basic administrative framework

It defines the administrative structure and boundaries of the protected sites, their cadastral structure and that of the adjacent territories, as well as their functional designation according to the urban and land-use plans in force. In the administrative division of the city all three of the protected sites are within the Central region of the city. According to the current Master plan of Plovdiv they are functionally part of the green recreational system of the city with the statute of public access parks. The specific functional designation set by the urban plan limits all future activities in these areas except for nature protection, sports and other recreation activities. The surrounding areas are with housing and public service functions (see Figure 1).

Anthropogenic factors and constraints

The survey on the anthropogenic factors and development constraints includes a detailed analysis of all anthropogenic developments, all the technical, recreational and access infrastructure together with analysis of the social functions of the territories as urban parks. As part of the urban structure the three protected sites are designated as public access recreational territories (urban parks). Their current usage and their function up till now has always been related to the daily recreational needs. As such all of them have well developed technical and access infrastructure which could normally serve the whole territory of the parks (with some renovations necessary at certain sections). Most of the recreational park infrastructure also needs some renovation. All three of the study sites have well developed water-supply infrastructure and some (at least partial) irrigation systems. Both of these systems however need reconstruction and/or renovation. All elements of the technical, the recreational and the social infrastructure were included in the GIS model as part of the land-cover model which than served as a basis on which the environmental and ecological habitat models were built up. The land-cover models of each the three hills are visually presented in Figure 2. The territorial balance of the three sites including the areal coverage of each of the territorial elements is summarized in Table 1.

Environmental factors and constraints. As part of the study all biotic and abiotic components of the natural and anthropogenic environment were reviewed. As abiotic components the analysis studied the available air quality data, climate and microclimate conditions, water, soil, geological and geomorphological environment, acoustic environment and electromagnetic and ionizing radiation data. Most of these factors of the abiotic environment however do not have any significant influence on the management system as they are not in a position to directly impact the process of sustainable development. Therefore as environmental factors from here on the study refers mainly to the biotic conditions.

The ecological conditions in all three of the studied sites are significantly influenced by the substantial human interventions which have been taking place for tens and even hundreds of years already. Through the historic development of the city, many of the autochthonous vegetation species have been forced out and many new species have been introduced, thus forming completely new ecosystems – a mixture of apophytes andanthropophytes, some of which of high conservational value.

Phytocoenological diversity factors. The field surveys showed highest rate of biological diversity in the Mladezhki hylm protected site, where 352 plant species were recorded. In comparison in the Danov halm 228 species were recorded and in Bunardzhika – 330. This amount of species accounts for average of approximately 23-24% of all the species registered in the Plovdiv region according to Cheshmedzhiev & Vasilev (2009). The approximate composition of the plant species consists of 66-85% grass species, 7-14% shrubs and bushes and 7- 30 % trees. Most of the species belong to the Asteraceae, Fabaceae and Poaceae families. High is the percentage of the artificially introduced (“alien”) species – from 44% in Bunardzhika, 58% in Danov halm, up to 68% in Mladezhki halm.

In order to incorporate the data on biological diversity in the GIS model the vegetation territories of the three sites was divided in to separate polygons, each representing a separate vegetation area studied on the field. Each polygon in the GIS layers contains data on their species composition and biological diversity. As a visual representation of that all polygons are labeled (Figure 3) with a number corresponding to a certain position in the explanatory table, which then provides information of the exact species found in that polygon (the detailed explanatory tables are provided as a separate report in the management plans published here: http://goo.gl/0CzrSr). A separate layer was then created to represent the exact location of the species of high conservational importance. This layer is visualized in Figure 4.

Ornitological diversity factors. The survey showed a moderate ornithological diversity in the three study sites, which is to be expected having in mind their location. The highest number of species were recorded at the Mladezhki halm – 50 species, belonging to 11 biological orders and 24 families. As a comparison, in the Danov halm only 33 bird species were recorded and in Bunardzhika – 37. Both Danov and Bunardzhika are much smaller in size and in even more densely populated area than Mladezhki halm. Most of the recorded species are of the order Passeriformes (22 species in Danov, 24 in Bunardzhika and 32 in Mladezhki halm). Comparatively high numbers also have the birds of Columbiformes and Strigiformes orders (3-4 species each). The single observations of birds are not part of the GIS model. They don’t have any spatial importance as development factors, because of their specific nature and their high mobility as a biological group. That is why the spatial model contains only an indirect representation of the habitats, suitable for those birds as parts of the vegetation areas or the rock formations, but with no direct spatial indication of the species observed on the field.

Invertebrates. The diversity of the terrestrial invertebrates was assessed by the number of insects (Insecta) and mollusks (Mollusca) found during the surveys. The number of species recorded in Mladezhki halm was 186 (consisting of 62 families and 12 orders), in Bunardzhika – 134 species (52 families and 11 orders) and in Danov haml – 82 species (of 41 families/9orders). The invertebrates recorded in the three sites are common, widespread inhabitants of this region and very few of them have any conservational importance. Such are the snail *Bulgarica fraudigera* (Rossmässler, 1839), a

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Bulgarian endemite, recorded on Bunardzhika hill and the spider *Eresus cinnaberinus* (Olivier, 1789), a vulnerable species (under IUCN), recorded on the Mladezhki halm. (Figure 5)

Amphibians and reptiles. The field surveys registered 2 amphibian species: *Bufo viridis* and *Hyla arborea* and 4 reptiles: *Mediodactylus kotschyi, Lacerta viridis, Podarcis tauricus,* and *Dolichophis caspius* (Figure 6 and 7, Table 2). Three more reptile species were registered in the same study sites in a in a previous survey (Mollov, 2005) - *A. kitaibelii, L. trilineata* and *P. muralis*. All registered species have high conservational value with the statute of “strictly protected fauna species” under Appendix II of the Convention on the conservation of European wildlife and natural habitats.

Terrestrial mammals. During the field surveys 4 mammal species were recorded in Danov halm (*Talpa europea* Linnaeus, 1758; *Sciurus vulgaris* Linnaeus, 1758; *Mus musculus domesticus* Schwarz, Schwarz, 1934 and *Rattus rattus* Linnaeus, 1758). In Bunardzhika hill and in Mladezhki halm the number of mammal species was higher – 9 species in Bunardzhika and 8 in Mladezhki halm. In addition to the ones registered in Danov halm here the surveys encountered also the white-breasted hedgehog (*Erinaceus concolor* Martin, 1838) and two mice species (*Apodemus (Sylvaemus) sylvaticus* Linnaeus, 1758 and *Apodemus (Sylvaemus) flavicollis* Melchior, 1834). Through the questionnaire method carried out with inhabitants living near the Bunardzhika hill the survey shows possible presence of two other species – the least weasel (*Mustela nivalis* Linnaeus, 1766) and the european polecat (*Mustela (Putorius) putorius* Linnaeus, 1758). Both of these species are of high conservational value and further detailed surveys are needed to confirm their presence and to assess their population.

Bats. Based on the field survey results and the available data from previous surveys (Tilova et al., 2008, Stoycheva et al., 2009) in the same region the 14 bat species were registered as certain or as probable inhabitants of the three studied sites. Two species (*Pipistrellus pipistrellus* and *Tadarida teniotis*) were confirmed in person on the field in Danov halm. Three species were registered in Bunardzhika - *Nyctalus noctula* (Schreber, 1774), *Tadarida teniotis* (Refinesque, 1814) and *Plecotus austriacus* (Fischer, 1829) and two - in Mladezhki halm (*Pipistrellus kuhlii* (Kuhl, 1819) and *Nyctalus noctula* (Schreber, 1774). All bat species have high conservational status – all species present in Bulgaria are protected under the Biological diversity act as well as under the Bern Convention, Bonn Convention and the UNEP/EUROBATS agreement. Suitable bat habitats in the three study sites are visualized in Figure 8.

Functional zoning. The spatial representation of the territorial development factors and constraints of environmental, ecological and anthropogenic nature was used to develop site-specific functional zoning of each of the three study sites. The specific areal coverage of each of the functional zones and the corresponding regime in each of them was based on the available resources, its conservational value as natural habitat, as a historical monument and its recreational and socio-cultural value.

In Danov halm three functional zones were defined 1) zone A (service area) – the zone is of the lowest environmental conservation regime. The zone hosts the major public service establishments in the site (open-air cinema, restaurant, caffee, etc.). The vegetation here is of predominantly decorative type. 2) zone B (higher zone) – having average conservation regime. The vegetation here is of semi-natural type with many decorative species. 3) zone C – conservational area - the zone with highest concentration of autochtonic and conservationally important species. (see Figure 9).

Similar is the functional zoning of Bunardzhika hill. Four functional zones were defined:

1) zone 1 – “park zone” – zone of typical urban recreation functions with predominantly decorative species and water effects; 2) zone 2 (forest-park zone) – transitional zone between predominantly decorative species to ecosystems of semi-natural type. 3) zone 3 - “high zone”- the territory of highest conservational value (nature conservation activities are the highest priority) and 4) zone 4 – memorial zone - a zone of anthropogenic influence dominated by the culture-historic memorial monuments and structures. (see Figure 10).

In Mladezhki halm two general functional zones were defined – zone 1 “lower” recreational zone with typical public use park functions and two subzones – zone of “attractions” (restaurants, sports establishments etc.) and zone of “recreation” – with typical park infrastructure. The second zone – higher “forest-park” zone is of higher conservational importance and it also consists of two subzones – a “forest-park” zone of semi-naturalistic type and a “special protection” zone with strict conservaton regime similar to that of the natural reserves. The functional zones are visually represented on Figures 9, 10 and 11.

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Table 1. *Land-use and territorial elements in Danov halm*

Territorial elements	Area [dka]	Percentage of the whole territory [%]
	Danov halm	
Green areas	28.08	52.11
Rock formations	12.91	23.97
Water areas (water effects)	0.06	0.11
Vegetated platfroms	1.38	2.57
Paved alleys / asphalt alleys	9.35	17.36
Public service establishments	0.49	0.92
Art and culture establishments	1.13	2.09
Cultural monuments (watchtower)	0.02	0.03
Communication infrastructure	0.24	0.44
Technical infrastructure	0.19	0.35
Public service infrastructure	0.02	0.05
Total coverage – Danov halm:	*53.88*	*100*
	Bunardzhik tepe	
Green area	145180.4	65.89
Water areas (water effects)	445.9457	0.2
Water areas (dirches)	127.3538	0.06
Paved and asphalt alleys / staircases, etc.	28500.31	12.93
Paved platforms	7265.434	3.3
Vegetated platforms	5465.609	2.48
Rock formations	6710.466	3.05
Vegetated rock formations	16334.77	7.41
Sports facilities	2116.584	0.96
Monuments	139.6315	0.06
Public service establishments	4503.051	2.04
Public service infrastructure (public toilets)	*66.0194*	0.03
Storehouses	109.0395	0.05
Technical infrastructure	1379.228	0.63
Electrical posts	*36.61551*	
Waterstorage	*1308.007*	
Pumping stations	*34.60503*	
“Grazhdanska zashtita” establishments	98.18721	0.04
Alien Streets	*1352.172*	0.61
Housing areas	558.046	0.25
Total coverage – Bunardzhik tepe:	*220352.3*	*100*
	Mladezhki halm	
Green areas	293507.25	80.78
Rock formations	13742.11	3.78
-vegetated rock formations	*3363.38*	*0.93*
-other rock formations	*10378.73*	*2.86*
Alleys/platforms/staircases	37735.01	10.39
Water areas (water effects)	1375.82	0.38
Sports facilities	6301.01	1.73
Public service infrastructure (public toilets)	113.6	0.03
Technical infrastructure	2016.92	0.56
-water storage	*9.94*	*0*

Territorial elements	Area [dka]	Percentage of the whole territory [%]
-electrical posts	*37.780397*	*0.01*
-pumping stations	*1969.203125*	*0.54*
Communication infrastructure	52.46	0.01
Public service establishments	88.88	0.02
Art and culture	109.33	0.03
Other buildings (currenty unused)	113.87	0.03
Railway	1015.97	0.28
Railway station	40.84	0.01
Access street	1286.82	0.35
Military terrain	5837.89	1.61
Total coverage – Mladezhki halm:	*363337.78*	*100*

Table 2 *Amphibian and reptile species registered in the studied sites*

Species	Study sites		
	Mladezhki halm	Bunardzhika	Danov halm
Bufo viridis	+	+	-
Hyla arborea	+	-	-
Mediodactylus kotschyi	+	+	+
Lacerta viridis	+	+	-
Podarcis tauricus	+	+	-
Dolichophis caspius	+	-	-

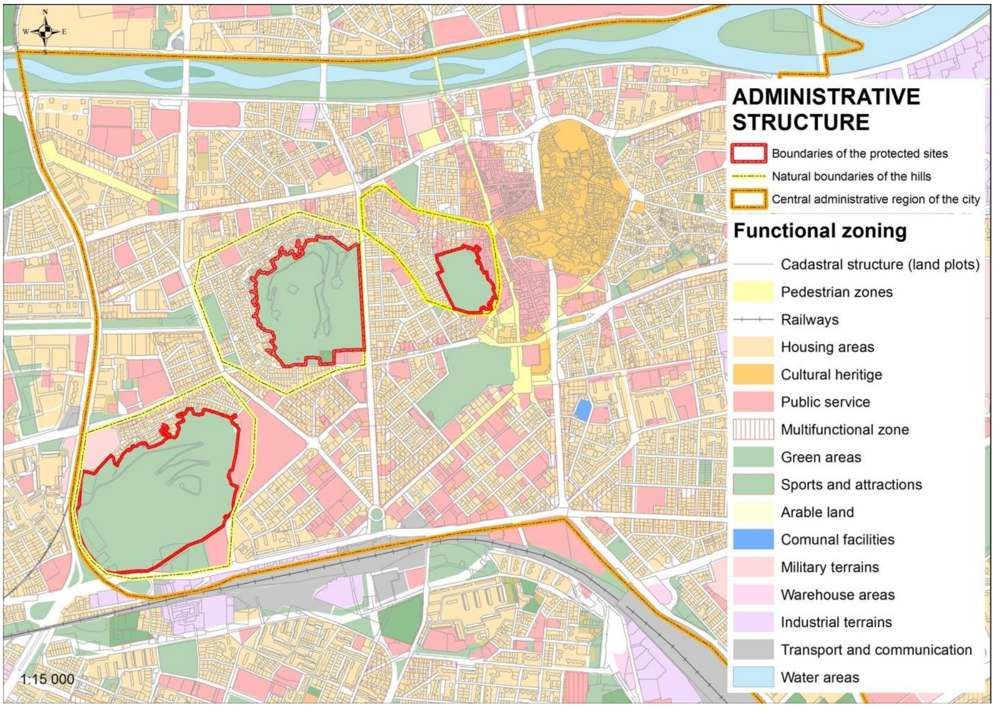

Figure 1. *Administrative structure of the adjacent territories.*

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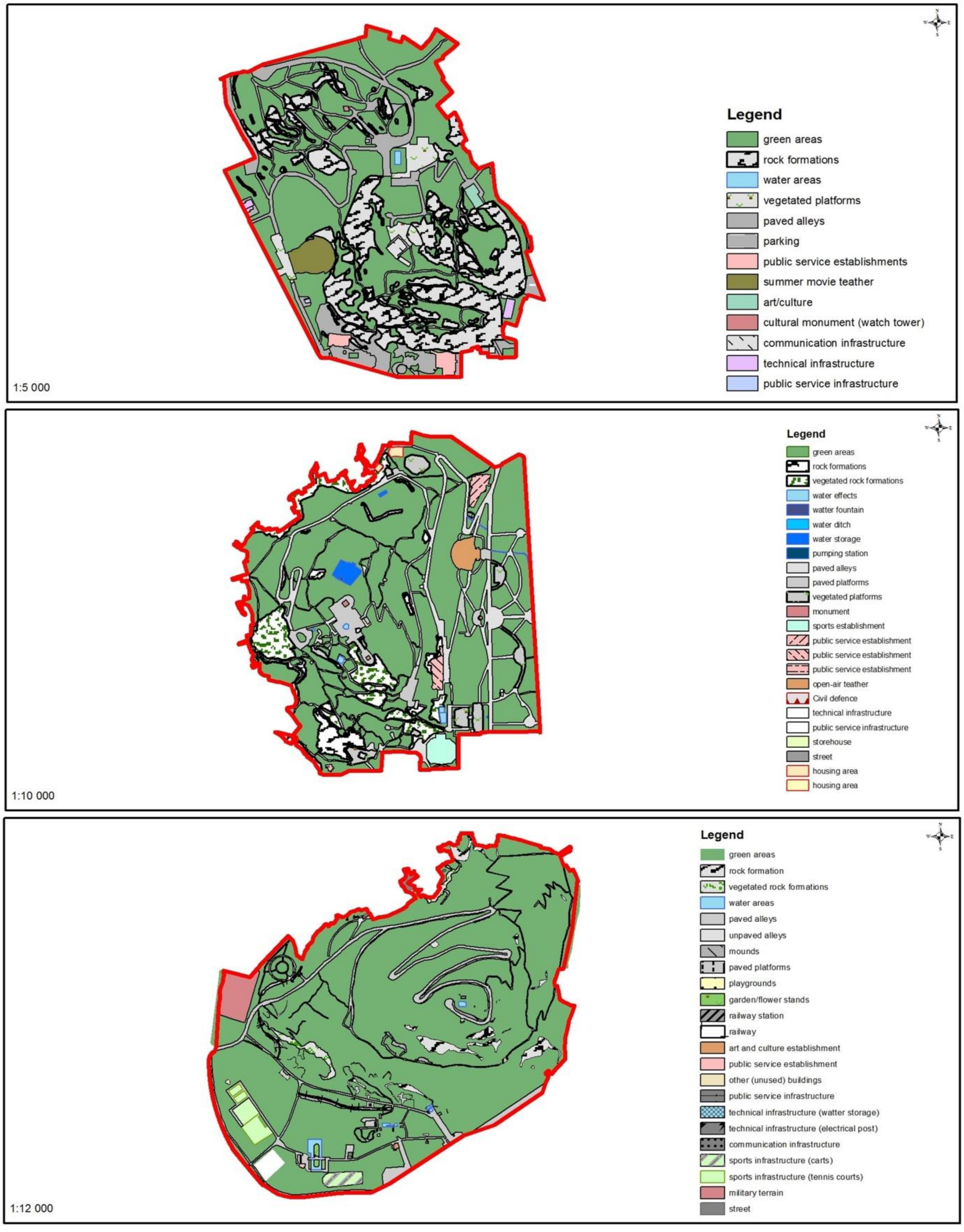

Figure 2. *GIS model of the land-use and territorial elements in the three study sites.*

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Figure 3. *Visual representation of the phytocoenological geo-informational model*

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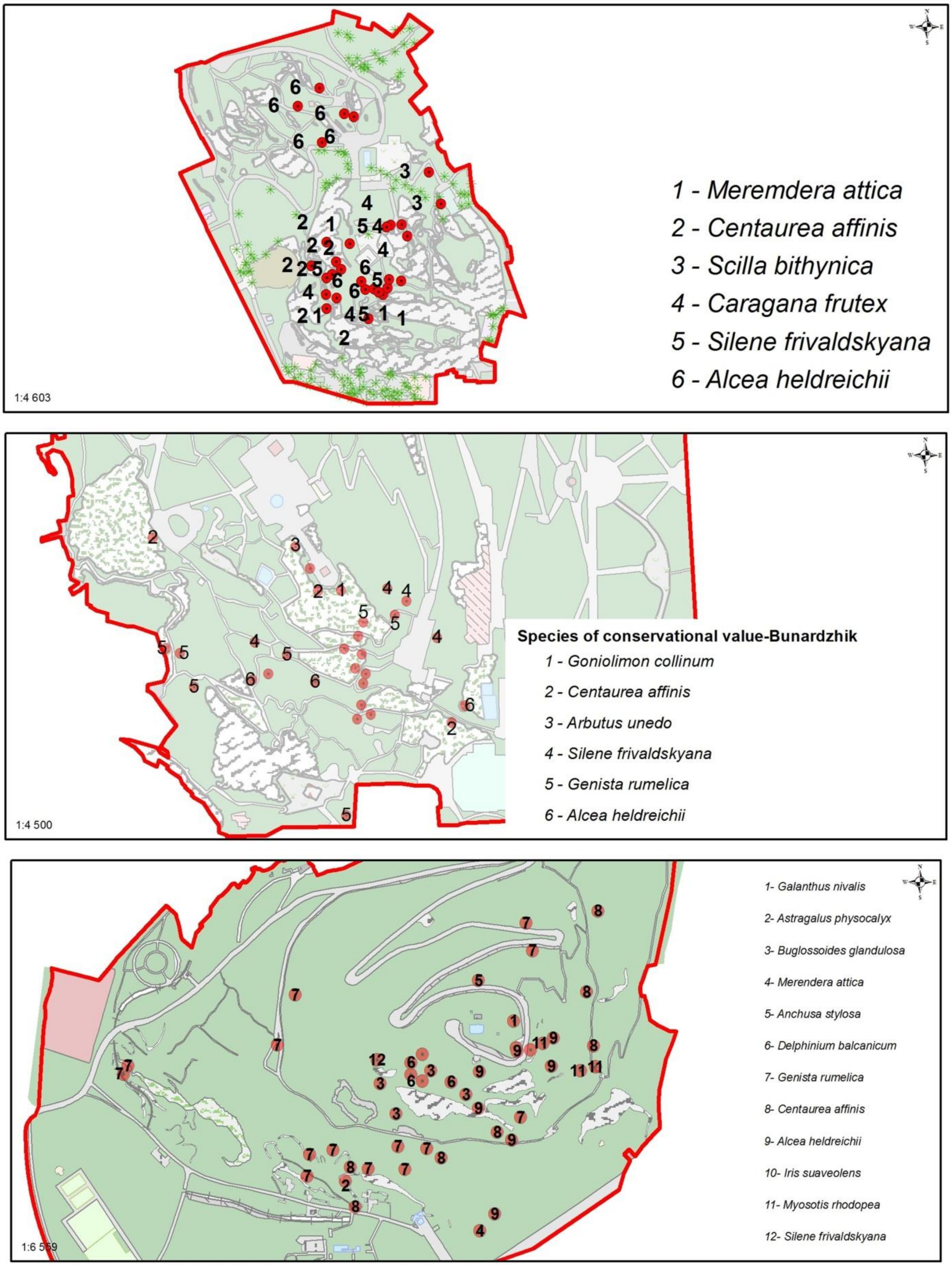

Figure 4. *Local distribution of the plants with high conservational value.*

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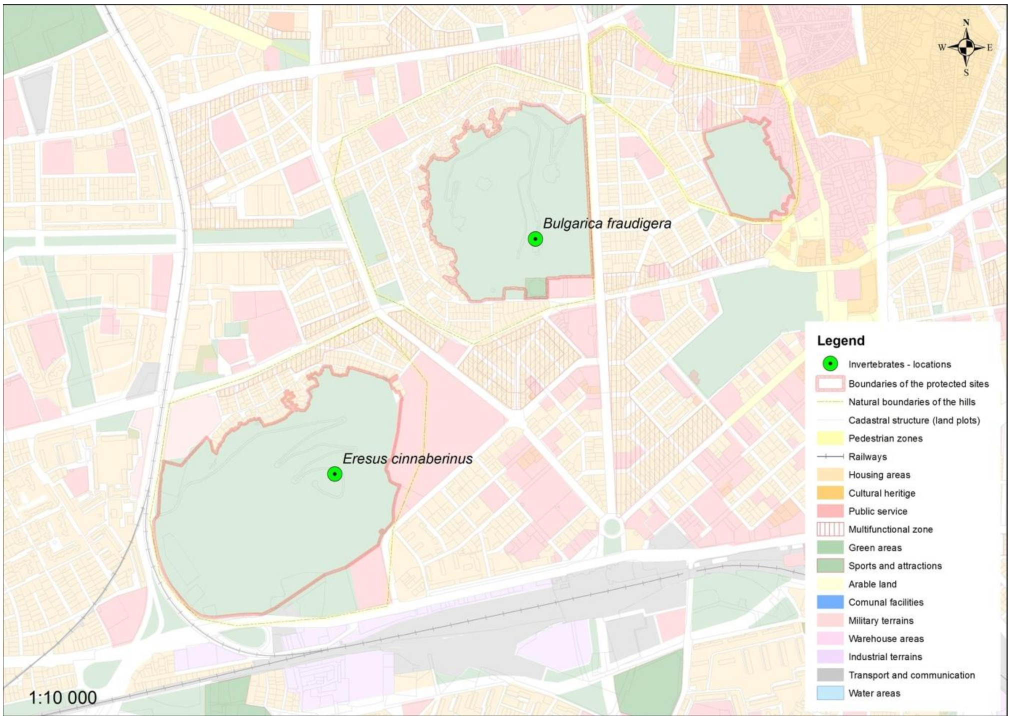

Figure 5. *Localization of the invertebrates of higher conservational value.*

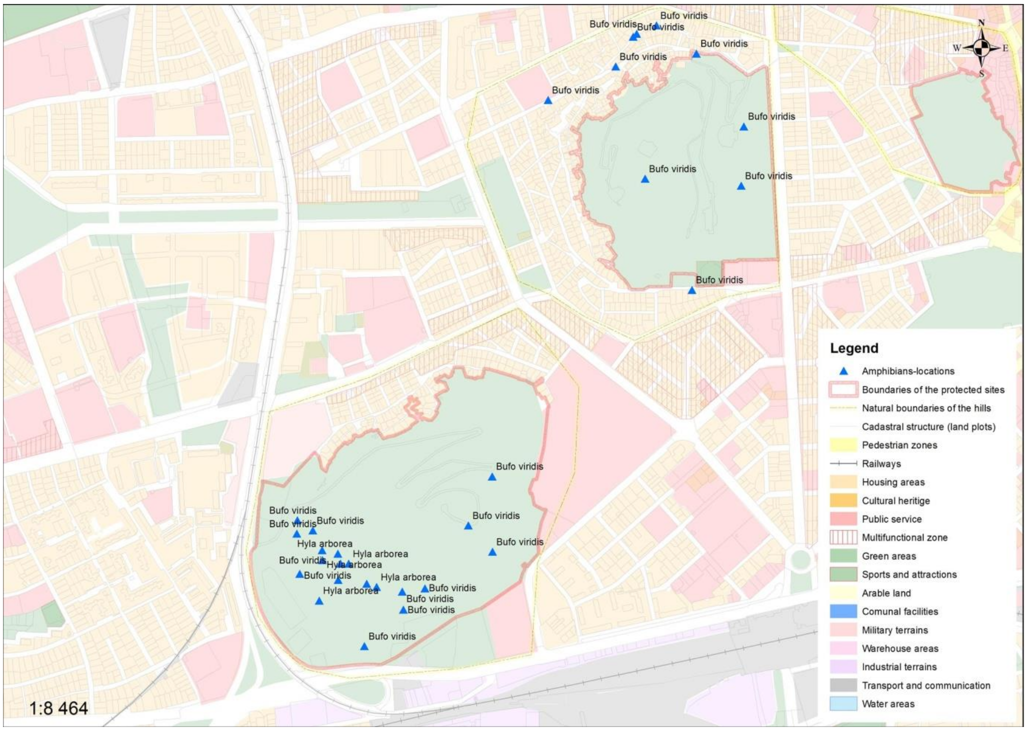

Figure 6. *Localization of the amphibians of high conservational value.*

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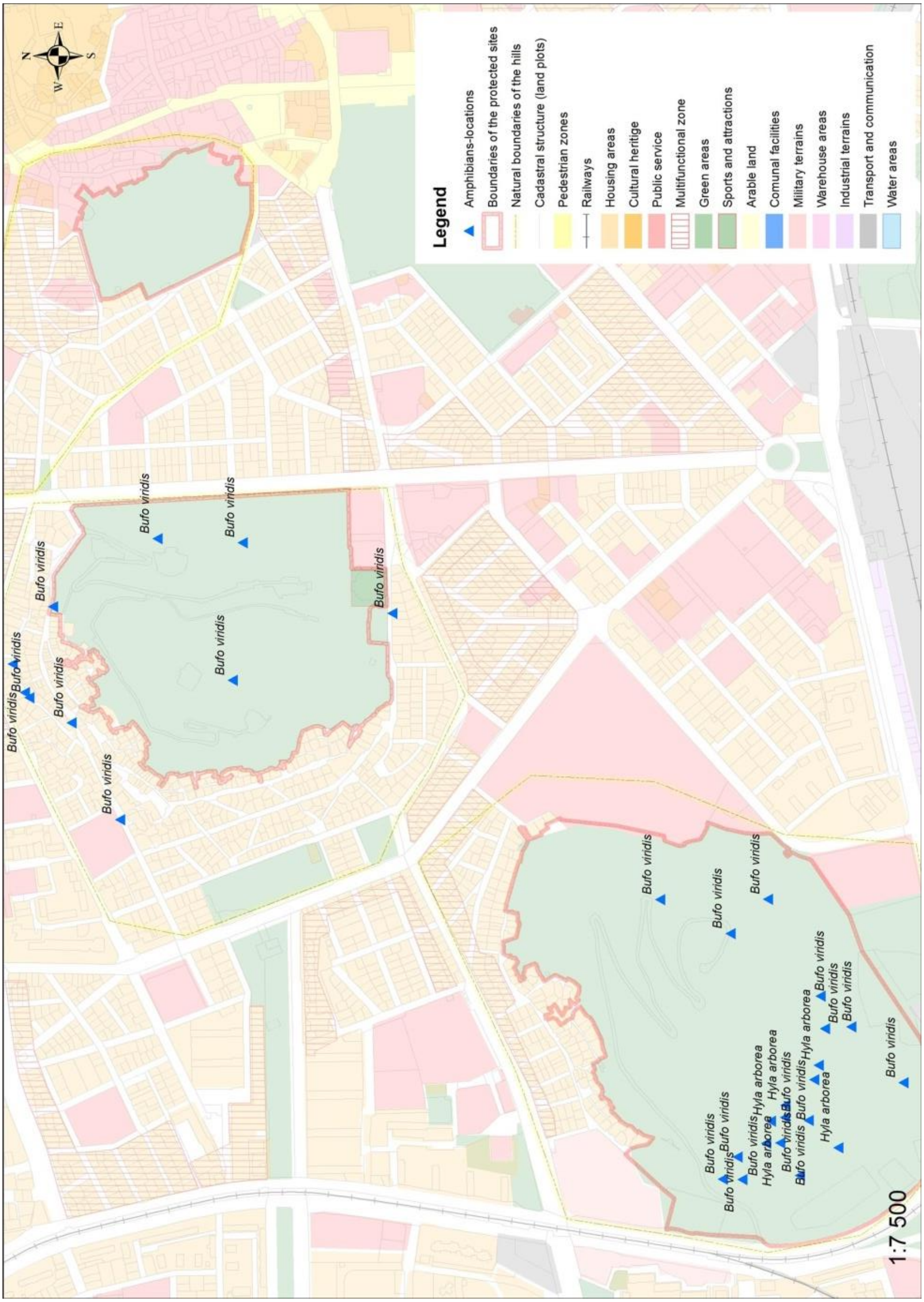

Figure 7. *Localization of the reptiles of high conservational value*

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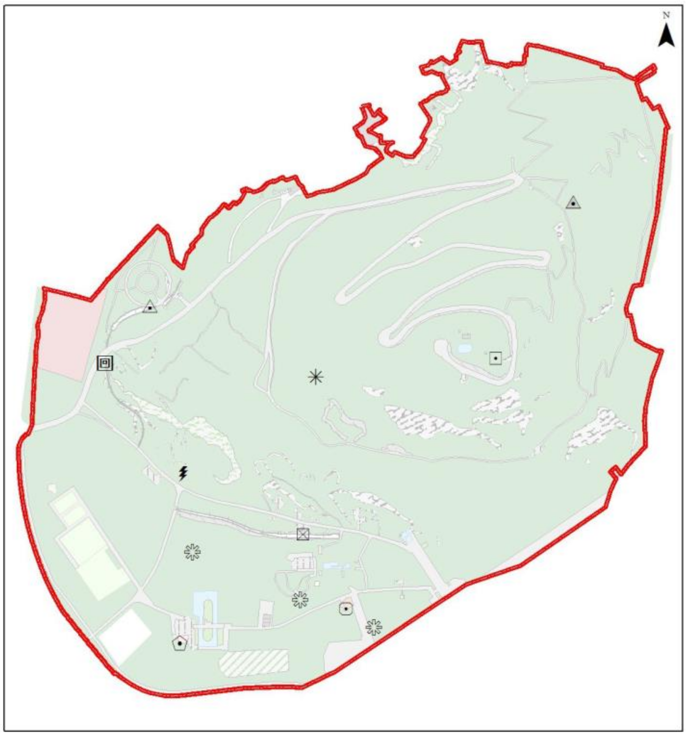

Figure 8a. *Suitable bat habitats in Mladszhki halm*

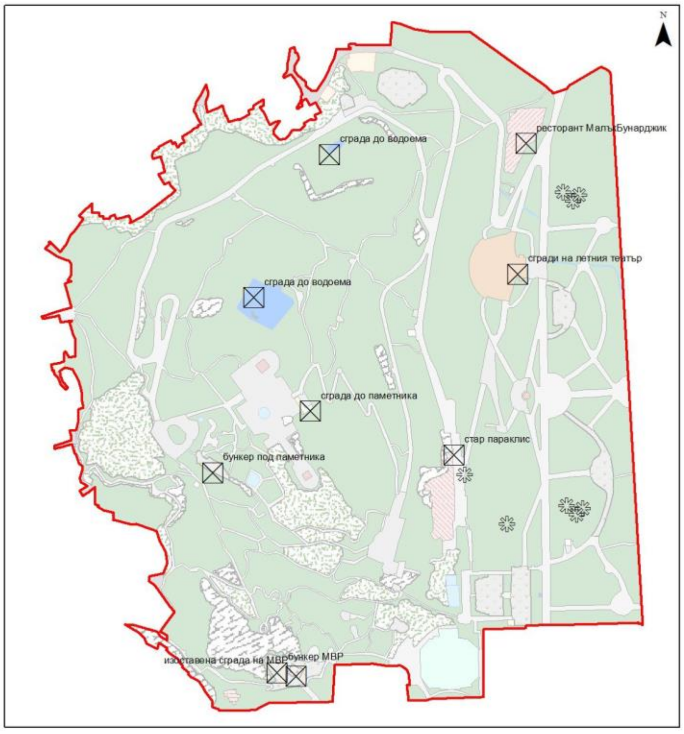

Figure 8b. *Suitable bat habitats in Bunardzhik tepe*

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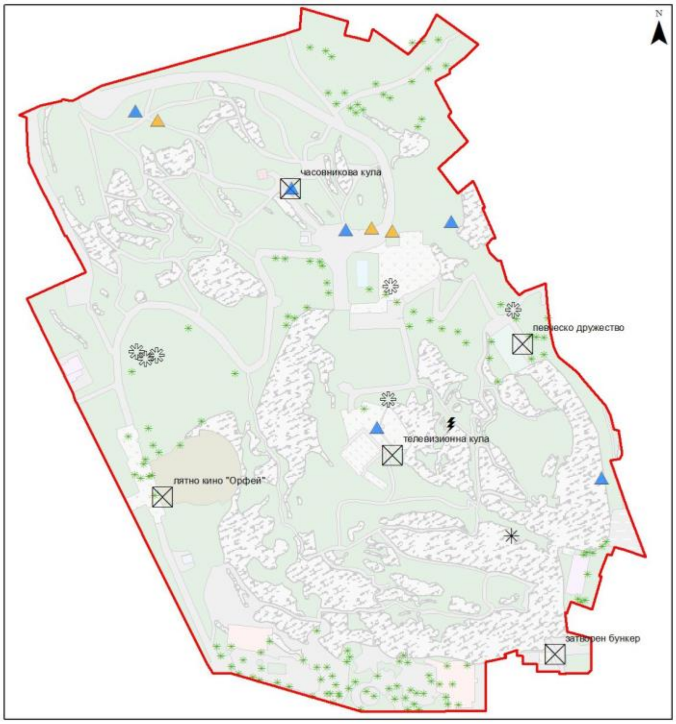

Figure 8c. *Suitable bat habitats in Danov halm*

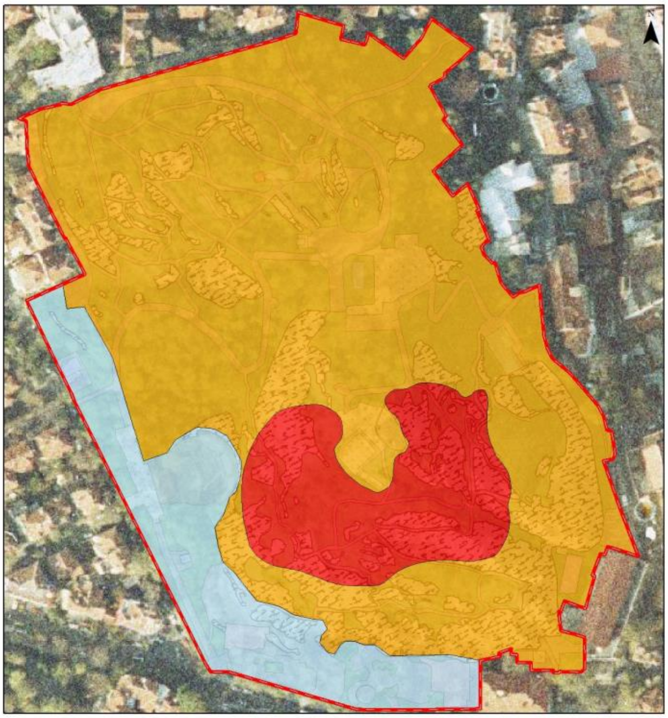

Figure 9. *Functinal zones in Danov halm*

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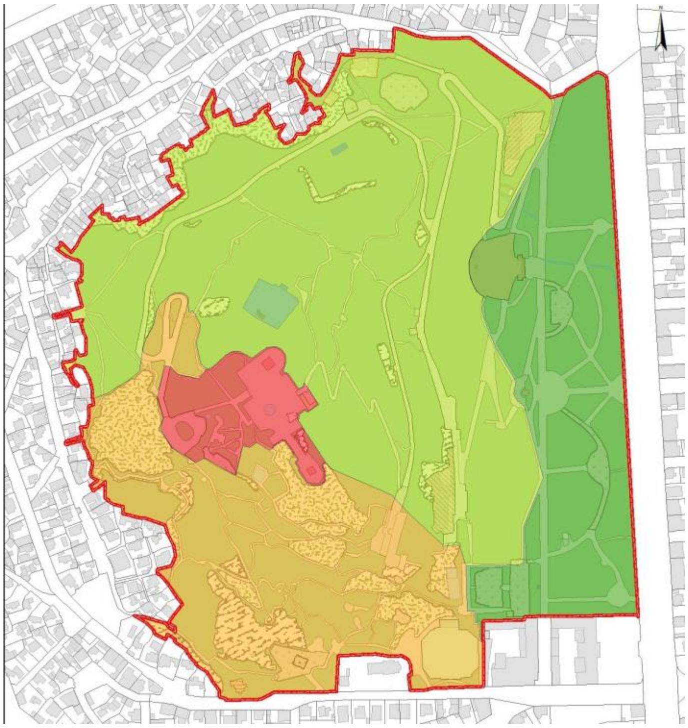

Figure 10. *Functinal zones in Bunardzhik tepe*

Figure 11. *Functinal zones in Mladezhki halm*

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Discussion

The usage of geo-informational models is a comparatively new instrument in the territorial systems management process in Bulgaria. However, in complex multifunctional territories such as the ones in the study sites, where the nature protection requirements should be developed together with the social and recreational functions of the territory such models prove to be an irreplaceable tool for spatial management. It gives the possibility to territorially localize all the development factors – drivers and constraints, influencing both the natural and the socio-economical aspects of its sustainable development. This is especially valuable in cases when some of these factors have different effect on the separate development aspects of the site. Most of the environmental factors described above for example, have twofold influence on the overall system. On one hand the biological diversity and the higher conservational value of certain species and their habitats would require certain development restrictions and a number of monitoring and supportive activities which would be of somewhat negative influence as economic constraints. On the other hand however, the high conservational value of certain species and habitats could also be a great asset and a strong positive factor for the development of the environmental protection aspect of the managed territory, thus enhancing not only the natural conservation importance of the site, but also its recreational and cognitive value.

As it was illustrated above the development constraints and driving factors of are of various nature. Their overlapping and sometimes controversial areal coverage could sometimes make a very complex picture of interactions. That is why the investigation the territorial influence and areal coverage of the development factors is a key and irreplaceable step for sustainable management such territories.

Acknowledgement

The study was carried as part of the work on development Management plans of the three natural monuments (Danov halm, Bunardzhik and Mladezhki halm). The development of the management plans was financed by the Municipality of Plovdiv (as a management authority of the three protected sites).

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