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Vulnerability Assessment of Wild Medicinal and Aromatic Plants Along the Bulgarian Black Sea Coast Using Rapid GIS-Based Model

Stoyan Vergiev
Department of Ecology and Environmental Protection
Technical University of Varna
Varna, Bulgaria
stvergiev@gmail.com

***Abstract*—The Bulgarian Black Sea coast is characterised by a high and specific biodiversity, acting as a critical conservation area for species within both the Balkan Peninsula and Europe. Wild medicinal and aromatic plants represent not only a vital ecological resource but also a significant Bulgarian export. Despite existing regulatory frameworks, the uncontrolled harvesting of non-protected species and species with conservation status exceeding permitted quotas persists. The combination of these practices and anthropogenic pressure, results in cumulative negative impacts on habitats, loss of localities, depletion of communities, and substantial long-term economic consequences. The Bulgarian strategy for the sustainable use of biological resources is based on the rigorous assessment and monitoring of the distribution, abundance, and population dynamics of wild species. Constantly changing market demands for specific quantities and types of medicinal plants, alongside evolving negative anthropogenic factors, require deploying dynamic, GIS-based Rapid Model for Vulnerability Assessment of Medicinal Plants (RMVAMP). The aim of the present study is to conduct a vulnerability assessment of wild medicinal and aromatic plants along the Bulgarian Black Sea Coast. By incorporating objective criteria and weighted values within a GIS environment, natural localities and habitats along the Bulgarian Black Sea Coast were classified according to their degree of vulnerability and are visualised using a colour scale on a specialised map. High-vulnerable areas were identified, where the medicinal plant harvesting requires stricter regulation. The species analysis effectively identifies and categorised species in three groups: resilient, vulnerable, and highly vulnerable. The species identified as most vulnerable to overharvesting include *Pancratium maritimum* L., *Leucojum aestivum L.*, *Orchis morio* L., *Orchis purpurea* Huds., *Paeonia peregrina* Mill., *Platanthera bifolia* (L.) L. C. Rich., *Ruscus aculeatus* L., *Ruta graveolens* L., and *Ephedra distachya* L.**

Keywords— Medicinal Plants, Eastern Bulgaria, Bulgarian Black Sea Coast, Vulnerability Assessment.

I. Introduction

Over the last decade, Bulgaria has faced a marked transition in the utilization of medicinal plants, as traditional harvesting for personal use is increasingly supplanted by large-scale commercial extraction for export [1], [2]. The increasing demand for raw materials within the pharmaceutical and cosmetic industries, combined with a drive for rapid economic returns, has placed natural populations under significant anthropogenic impact [3]. Despite existing regulatory frameworks, illegal harvesting and the systematic exceeding of quotas remain critical challenges that threaten Bulgaria's biodiversity, which is a key renewable resource [4].

Illicit harvesting, combined with extensive and regional-scale anthropogenic stressors, exerts a cumulative negative impact on natural habitats [2], [5]. In accordance with established scientific frameworks for the sustainable management of Bulgaria's bioresources, comprehensive monitoring of the occurrence, abundance, and population fluctuations of wild species is essential to ensure long-term resource sustainability [4], [6], [7]. Effective bioresource management relies on high-quality quantitative data, obtained from long-term studies of exploitation pressures. As environmental and market conditions evolve, the development of adaptive models becomes crucial for the spatial-temporal evaluation of vulnerability in medicinal and aromatic plants [4].

The Bulgarian Black Sea coast represents a heterogeneous mosaic of ecosystems and is characterised by a high and specific biodiversity. The coastal area acts as a critical conservation area for species within both the Balkan Peninsula and Europe and provides habitats and critical refuges for a variety of rare medicinal and aromatic taxa that are increasingly pressed by intensive tourism and rapid urbanization [4]. Implementation of models along the entire coastal area facilitates the identification of critical

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"hotspots" where biodiversity is affected by unregulated harvesting and habitat degradation.

One of the most established global scale tools for analysing and assessing the overexploitation of medicinal plants is the Rapid Vulnerability Assessment (RVA), which has been validated and tested in series of studies [8] - [11]. Modern conservation strategies require enhancing and expanding this model in order to incorporate not only species-specific assessments but also a holistic analysis of entire communities and habitats. Unlike the RVA model, its adaptation, the "Rapid Vulnerability Assessment Model for Medicinal Plants" (RMVAMP) [4], [5], [12] relies on a combination of additional criteria to better prioritise of conservation zones on regional and local scale. Well-defined criteria, integrated within a GIS environment enable dynamic scaled assessments and habitat mapping based on extensive datasets [4], [5], [13].

The aim of the present study is: 1) to conduct a vulnerability assessment of wild medicinal and aromatic plants along the Bulgarian Black Sea Coast, 2) to classify natural localities and habitats according to their degree of vulnerability, visualised using a colour scale on a specialised map, 3) to identify high-vulnerable areas where medicinal plant harvesting requires stricter regulation.

II. Material and Methods

The Bulgarian Black Sea coast is characterised by a unique climatic transition from temperate continental to sub-Mediterranean conditions from north to south. The strong maritime influence causes milder winters and specific humidity levels, favouring the spread of rare medicinal and aromatic plants [14]. The northern Dobrudja Plateau is dominated by intensive agriculture, leaving wild medicinal plants confined to fragmented steppe habitats and field margins. In contrast, the southern reaches around Burgas and the Strandzha massif are defined by extensive forests and higher humidity, supporting a greater density of woodland species. The investigated area faces rapid urban overdevelopment and infrastructure expansion. This coastal sprawl is the primary driver of habitat fragmentation, necessitating urgent spatial management to protect both rare and common plant populations [4], [5], [13].

To map the study area, five-step GIS workflow that integrated field data with spatial modelling tools was developed (Fig. 1). The Input Data phase integrated heterogeneous datasets, including biodiversity inventory based on existing literature records, historical distribution data [15], [16], [17], and precise GPS coordinates collected during field surveys and remote sensing methods covering the vegetation periods from 2008 to 2024. These inputs were processed to generate Species Distribution Vector Polygons, delineating the precise spatial boundaries of each target taxon.

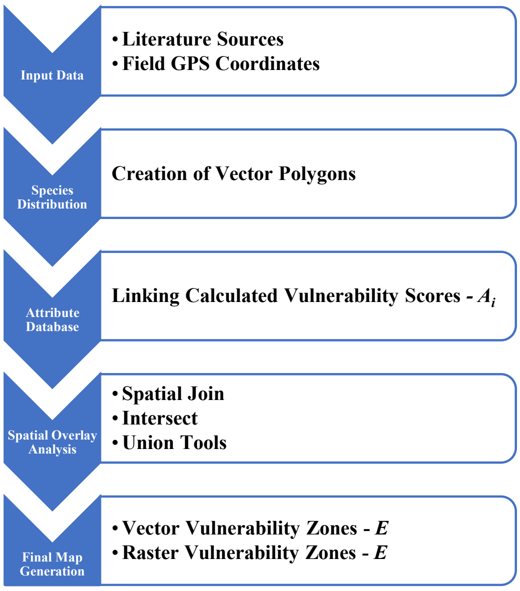

Fig. 1. Methodological GIS workflow diagram of the RMVAMP framework for spatial vulnerability assessment.

Attribute Tables were constructed and linked to the vector geometry, populating the database with the calculated integral vulnerability scores (A_i) for each species.

Conservation status, as well as endemic and relics designations, were determined after [16], [18]. The international conservation status of taxa was determined based on Annexes II and V of Directive 92/43/EEC (Habitats Directive), Annex I of the Bern Convention, and Annex II of the CITES Convention (the Convention on International Trade in Endangered Species).

A regional-level plant species assessment scheme based on the Rapid Vulnerability Assessment (RVA) method [8] - [11], [19], [20], modified by Vergiev [4], [5] was applied. The model includes two main groups of criteria: biological (distribution and conservation status) and socioeconomic factors. The vulnerability of each taxon is determined by ten predictors, each assessed on a point scale from 0 (not applicable) to ascending values reflecting an increasing degree of threat.

The integral score for each taxon is calculated as a weighted sum of the values for the ten criteria. The mathematical model applies specific weighting coefficients to the points awarded for each parameter according to the following formula:

$$A_i = \sum_{j=1}^{10} w_j \, . \, C_{ji} \qquad (1)$$

where,

A_i – general vulnerability assessment of the taxon i

w_j – coefficients of significance of the criterion j (shown in Table 1)

C_{ji} – estimate score of criterion j for taxon i.

TABLE 1 SUMMARY SCHEME OF CRITERIA FOR THE ASSESSMENT OF PLANT TAXA MODIFIED AFTER [4], [5], [21], [22].

Code	**Criterion**	
Coefficients	*Predictors*	*Score*
C1	Presence and distribution of the species in floristic regions and subregions of Bulgaria	
0.50	Only in the study region From 2 to 15 regions From 16 to 29 regions	5 1 0
C2	Population fragmentation	
0.50	Highly fragmented Low fragmented Unfragmented	5 3 0
C3	National conservation status (Included in the Bulgarian Biological Diversity Act)	
1.25	Included in Annex 2 Included in Annex 3 Included in Annex 4 Not included	3 3 2 0
C4	Red Data Book Criterion	
1.00	CR Critically Endangere EN Endangered VU Vulnerable NT Nearly Endangered LC Low Affected DD/NE, Insufficient Data, Not Rated N/A	4 3 2 1 0 0 0
C5	Endemics and Relics	
1.25	Endemic to Bulgaria Endemic to Bolcan Peninsula Relics N/A	5 3 2 0
C6	International conservation status criterion	
1.25	IUCN Directive 92/43/EEC Berne Convention CITES N/A	2 2 2 2 0
C7	Plant parts used	
2.00	Whole plants Roots, rhizome Flower, seed, and inflorescence Leaves	4 3 2 1
C8	Resource origin	
0.50	Only from wild Wild and trial cultivation Wild and small-scale cultivation Only from cultivation	4 3 2 1
C9	User group	
0.50	Local people, local exchange and trade Local people and trade Local people and local exchange Local people	4 3 2 1
C10	Life forms	
2.00	Long lived perennial Short lived perennial Biennial Annual	4 3 2 1

A spatial Overlay Analysis was performed using the Spatial Join and Intersect/Union tools to merge overlapping species polygons and calculate cumulative environmental pressure [12].

The workflow concluded with the Generation of the Final Vulnerability Map, producing a high-resolution vector/raster output that delineates and categorises the specific geographic zones based on their cumulative vulnerability index (E).

The final vulnerability assessment of a specific territory (E) shifts the focus from a simple species count to a spatial perspective, recognising that site vulnerability depends on both species richness and individual taxon sensitivity. It is calculated using the following formula:

$$E = \frac{\sum_{k=1}^{n} A_k}{n} \qquad (2)$$

where,

E – general vulnerability assessment of the territory

A – vulnerability assessment of each individual taxon k

n – total number of assessed taxa in the territory.

For map drawing, the following were used: UTM Zone 35 North map projection, WGS84 terrestrial coordinate system and the Baltic altitude system.

The reliability of the RMVAMP model was tested by conducting field checks across 15 randomly selected high-vulnerability zones. At each validation site, empirical field observations were conducted to assess actual habitat degradation, signs of overexploitation, and current anthropogenic pressure. These field-based metrics were then statistically compared with the model's predictive outputs, confirming a high degree of correlation between the theoretical vulnerability index (E) and the real-world anthropogenic impacts observed on the ground.

III. RESULTS AND DISCUSSION

A total number of 1846 plant species were recorded in the region is. This relatively compact territory accounts for 45.4% of all vascular plant life in Bulgaria. According to Medicinal Plants Act of the Republic of Bulgaria and subordinate legislation, 591 of these species were recognised as medical and aromatic plants and were subsequently assessed. This number is 32% of all inventoried species. Fifty-five species are assessed with high conservation status.

The Rapid Vulnerability Assessment (RVA) approach is based on the notion that a limited number of factors have a decisive influence on the sustainable use of medicinal plants. Typically, this assessment is calculated by summing 5 to 7 predictors, which allows for the rapid identification of species threatened by overexploitation. However, when a comprehensive analysis of a specific area is required, and not just individual taxa, simple summary of data is insufficient.

The RMVAMP model operates on the 80/20 Principle, recognising that a handful of critical factors often drive most ecological outcomes [23]. The model shifts the focus from a simple tally of species to a more spatial perspective, and the vulnerability of a specific site is more than just the sum of its plants. This represents a significant upgrade from the original RVA.

Unlike classical methods, the Rapid Vulnerability Assessment Model for Medicinal Plants (RMVAMP) builds on this model by integrating additional aspects and critical factors that directly affect the resources in the given area.

The predictors are structured into two main groups. The first covers ecological criteria, such as distribution, habitat fragmentation, and conservation status. Distribution is assessed according to the presence of the species in the different floristic regions of Bulgaria, based on the hypothesis that widespread taxa are more resilient. The degree of fragmentation of populations serves as an indicator of their ability to recover. Conservation status integrates four criteria (national and international), with the accumulation of protective categories increasing the vulnerability index.

The integration of high-weight predictors, such as the specific plant parts used (C7, weight 2.00) and life forms (C10, weight 2.00), ensured that the analysis was highly sensitive to the intrinsic biological capacity of the species to recover from harvesting stress. The extraction of roots and rhizomes, as well as whole plant harvesting is more invasive than that of foliage and other vegetative organs. Species that are obtained only from the wild or are used by a wide range of users are classified as more endangered. The assessment is based on a detailed inventory of the flora in the study area, compiled from literary sources and the author's field studies. The second group deals with socioeconomic status.

Although the model is aimed at identifying the vulnerability of individual locations, it can also be applied to identify the vulnerability of individual species. Based on the quantitative index scores (A_i), the 591 assessed species were successfully categorized into distinct vulnerability classes:

1) Vulnerable species: *Sedum acre* L. *Artemisia alba* Turra, *Helichrysum arenarium* (L.) Moench, *Galium odoratum* (L.) Scop., *Echinops sphaerocephalus* L., *Galanthus nivalis* L., *Glaucium flavum* Crantz, *Asarum europaeum* L., *Valeriana officinalis* L., *Convallaria majalis* L., *Cercis siliquastrum* L., *Frangula alnus* Mill., *Lilium martagon* L.

2) Highly vulnerable species: *Pancratium maritimum* L., *Primula veris* L., *Carlina acanthifolia* All., *Paeonia peregrina* Mill., *Asparagus officinalis* L., *Berberis vulgaris* L., *Alchemilla vulgaris* L. , *Leucojum aestivum* L., *Ephedra distachya* L., *Ruscus aculeatus* L., *Orchis morio* L., *Orchis purpurea* Huds., *Orchis simia* L., *Cyclamen coum* Mill., *Artemisia lerchiana* Weber, *Platanthera bifolia* (L.) L. C. Rich., *Ruta graveolens* L.

Cumulative weighted values were incorporated in GIS environment. The natural habitats in the Bulgarian Black Sea Coast were categorised into classes of vulnerability and were indicated on the created map using colour scale (Fig. 2).

Applying the constructed model and as a result of the "overlay" analysis, all values within the areas of overlap of the polygons were summarised and 53 zones of high vulnerability were identified.

The identification of areas with a degree of vulnerability is only the first step in a long and tough process of protecting the habitats of medicinal and aromatic plants. Our role as scientists is to investigate and to analyse, followed by prioritizing and using limited resources for the protection of medicinal plants. This should be accompanied by the implementation of the entire set of regulatory documents and punitive instruments for the preservation of natural habitats. In my opinion, educational initiatives are also extremely important to inform about the available medicinal plants in each area, along with small projects for the protection and expansion of habitats.

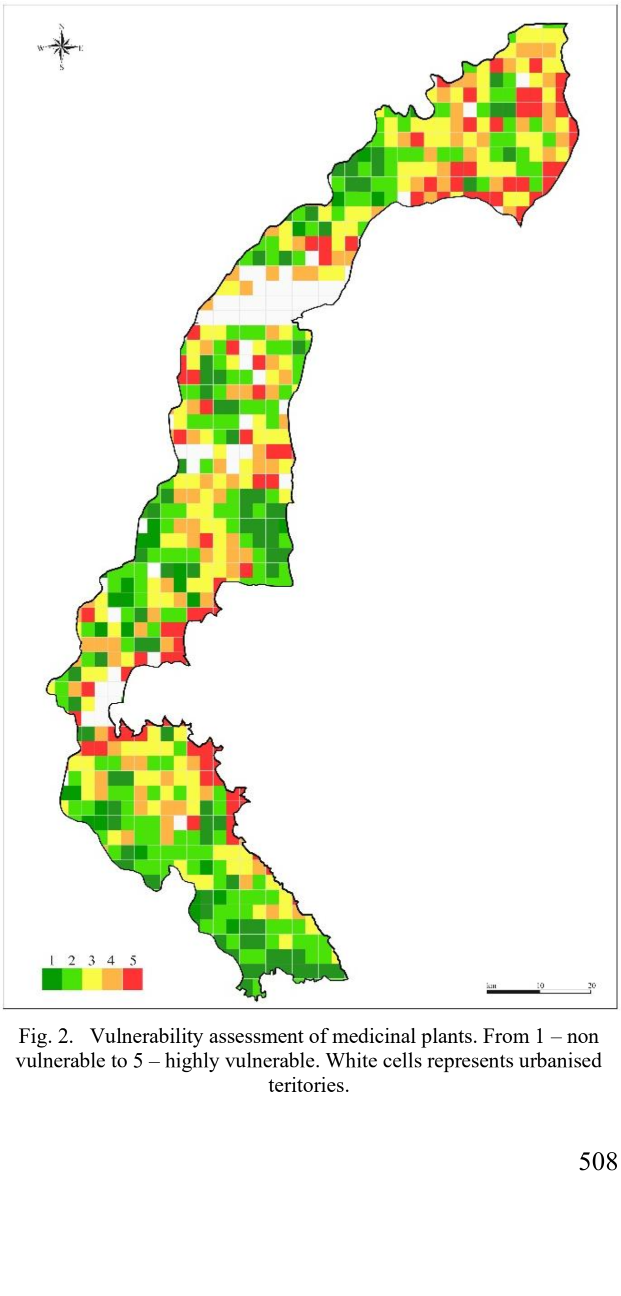

Fig. 2. Vulnerability assessment of medicinal plants. From 1 – non vulnerable to 5 – highly vulnerable. White cells represents urbanised teritories.

The practical utility of the RMVAMP framework lies in its ability to provide environmental managers and authorities with actionable spatial data. Traditional conservation plans often apply broad regional restrictions that can be economically inefficient and difficult to enforce. By contrast, the pinpoint accuracy of the 53 identified hotspots allows the Bulgarian Ministry of Environment and Water to deploy targeted conservation measures.

In these critical zones, we recommend the immediate implementation of temporary harvesting bans (quotas set to zero) for highly vulnerable species, paired with strict spatial monitoring during the peak vegetative and collecting seasons. To alleviate the pressure on wild populations within these hotspots, regional economic programs should incentivize small-scale, local cultivation initiatives (shifting species scores from 4 to 1 on the C8 resource origin scale). Ultimately, balancing scientific spatial modelling with strict legislative enforcement and community-based conservation projects offers the most viable path toward the sustainable management of Bulgaria's wild medicinal bioresources.

IV. Conclusions

This study demonstrates the application and theoretical framework of the GIS-based Rapid Model for Vulnerability Assessment of Medicinal Plants (RMVAMP) along the Bulgarian Black Sea Coast. By combining multi-criteria ecological and socioeconomic factors into a weighted mathematical matrix, the model successfully shifts resource evaluation from simple species counts to a dynamic spatial analysis. Cumulative assignment in more predictors defines species as more vulnerable.

The established total number of plant species found in the region is 1846. This relatively compact territory accounts for 45.4% of all vascular plant life in Bulgaria. According to Medicinal Plants Act of the Republic of Bulgaria and subordinate legislation, 591 of them were recognised as medical and aromatic plants and were assessed. This number is 32% of all inventoried species.

Cumulative weighted values were incorporated in GIS environment. The natural habitats in the Bulgarian Black Sea Coast were categorised into classes of vulnerability and were indicated on map using colour scale.

The present study validated the practical value of the framework, successfully delineating 53 high-vulnerability hotspots that require immediate regulatory intervention and stricter harvesting quotas. Future research will expand this GIS-driven workflow to cover the remaining northern and southern segments of the Bulgarian coast, establishing a unified spatial database for bioresource preservation.

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