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Medicinal and Aromatic Lamiaceae Plants in Greece: Linking Diversity and Distribution Patterns with Ecosystem Services

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Abstract: *Research Highlights:* This is the first review of existing knowledge on the Lamiaceae taxa of Greece, considering their distribution patterns and their linkage to the ecosystem services they may provide. *Background and Objectives:* While nature-based solutions are sought in many fields, the Lamiaceae family is well-known as an important ecosystem services provider. In Greece, this family counts 111 endemic taxa and the aim of the present study is to summarize their known occurrences, properties and chemical composition and analyze the correlations between these characteristics. *Materials and Methods:* After reviewing all available literature on the studied taxa, statistical and GIS spatial analyses were conducted. *Results:* The known properties of the endemic Lamiaceae taxa refer mostly to medicinal and antimicrobial ones, but also concern nutritional and environmental aspects. Essential oils compositions with high concentrations in molecules of interest (e.g., carvacrol, caryphyllene oxide, etc.) have been found in some taxa, suggesting unexploited applications for these taxa. Distribution patterns show a higher concentration of endemic Lamiaceae on the island of Kriti and southern Peloponnisos; patterns of the endemics' properties are also highlighted in the biodiversity hotspot of Kriti. However, the lack of data for two thirds of the taxa, regarding their properties or specific distribution, shows a gap of knowledge. Results on endemic Lamiaceae properties and composition are correlated with the supply or potential supply of ecosystem services and the relevant hotspots have been identified. *Conclusions:* The Greek endemic Lamiaceae taxa are proved to be of great importance, regarding their chemical composition and the properties they confer. The distribution analysis suggests the existence of clustering patterns of plant species with common properties. Finally, this study highlights knowledge gaps that should be filled in order to ensure the conservation of the endemic Lamiaceae taxa and the preservation of the ecosystem services they provide or could potentially provide.

Keywords: biodiversity management; endemic taxa; Greek flora; knowledge gaps; MAES implementation

1. Introduction

The biological resources of medicinal and aromatic plants have been used extensively for health care and healing practices across history and cultures [1–6]. Hundreds of millions of people, especially in developing countries and regions, collect plant and animal material to fulfil their needs for substances for personal uses or for trade as a complementary or primary income [7,8]. Characteristically, the World Health Organization reports that medicinal and aromatic plants still form the basis of traditional or indigenous health systems of the populations in most of the developing countries [9]. The collection and use of nature products and especially medicinal and aromatic plants is a common practice also in developed countries for cultural reasons as well as for trade commodities that meet the demand of often distant markets [10]. Moreover, medicinal and aromatic plants represent the largest natural resource (in terms of taxa number) used for its properties and compounds, especially in the growing, international market of plant-based cosmetics, spices, medicine and health products [11].

Subsequently, intensive pressure on natural resources is placed on the populations of the medicinal and aromatic plants, due to increasing demand, most of which are still collected in the wild. Uncontrolled overexploitation of wild plants, their habitat loss and alteration are the main reasons why medicinal plants, their study, evaluation, utilization and conservation have become essential parts of research programs [12] and increasing recommendations by many agencies that wild species should be brought into cultivation [13–15]. Although cultivation of medicinal plants can reduce the harvesting pressures on wild populations, it could also result to habitat and ecosystem degradation, genetic diversity reduction and the loss of incentives for the conservation of wild populations [16]. On the other hand, wild plant populations are affected by disturbance processes and positive links are identified among medicinal plant diversity and disturbance factors; the example of *Arnica montana* is typical, where traditional grazing practices in European meadows supports the conservation of rare plant populations [17,18].

The trade-off documentation (e.g., among conservation and production benefits) for medicinal and aromatic plant exploitation is crucial for supporting management decisions and policy-making processes on species conservation options and actions needed to be implemented [19–21]. In situ and ex situ conservation (field, seed and in vitro collections), which are complementary conservation strategies, are being implemented in Europe and other continents in the world for plant genetic resources in general, and medicinal and aromatic plants species in particular [22]. During recent decades, the demand and need for natural products and their substances, instead of safety-questionable synthetic compounds, has guided numerous studies regarding wild plant chemical composition, properties and uses [23–25].

The ecosystem services (ES) approach [26–28] recognizes that humans, characterized by their cultural and economic diversity, form an integral component of the natural environment. This strong relationship among human activities and ecosystems is the core of the sustainable development framework and highlights the dependence of human society on ecosystems [10,29], as well as that human and ecosystem "prosperity" need to be jointly assessed [30]. When the human condition and the condition of the ecosystem are favorable or improving jointly, then sustainable society functioning should be achieved [31,32]. Plant and animal population and distribution trends are indicators of sustainable resource use. Subsequently, a sustainable harvesting system, including medicinal and aromatic plants, proposes the collection of plant material from a certain area without impact on the structure and functions of the harvested plant population [33,34].

The capacity of nature to provide medicinal and aromatic plant resources depends on the species richness of medicinal/aromatic plants. Several areas in Europe and Central Asia are characterized by high medicinal plant species richness, including the Mediterranean region, the Alps and the Pyrenees, the Massif Central in France, the Balkan Peninsula, the Crimean Peninsula and the Carpathian Mountains [35]. Bogers et al. [36] concluded that the use of naturally available resources is of high priority in areas where climatic conditions and environmental attributes permit it, and Greece is considered as one of the globally important places where medicinal and aromatic plants constitute an important natural resource [37,38]. An outstanding example of a plant family with important medicinal and aromatic plants in Greece is the Lamiaceae, colloquially known as the "mint family"; it includes many ethnobotanically renowned species such as sages, thymes, lavenders, "mountain teas" and oreganos [39].

Under the key targets of the Mapping and Assessment of Ecosystems and their Services (MAES) implementation in Greece [40] and in the frame of the currently in progress Flora of Greece project, this paper provides an overview of the endemic Lamiaceae medicinal and aromatic plants of Greece, by using all the available literature data for each taxon's uses and attributes. More precisely, this work aims to: (a) provide a catalogue of the endemic Lamiaceae medicinal and aromatic plant species and subspecies (taxa) with country-wide distributional data, assigned to ecosystem types and followed by their properties and components characteristics, (b) summarize the distribution patterns for Lamiaceae medicinal and aromatic plants in Greece, (c) highlight diversity and endemism hotspots for the Lamiaceae plants, (d) support MAES implementation, by assigning each taxon to the actual or potential supply of one or more ecosystem services and (e) pinpoint data gaps and further steps needed for the sustainable exploitation and management of medicinal and aromatic plants' wild populations.

2. Materials and Methods

The Lamiaceae taxa present in Greece and their status as Greek endemics and/or range-restricted are identified and designated following Dimopoulos et al. [41,42] and the related Flora of Greece Web database portal [43]. In the present study, taxa are defined as comprising species and subspecies. Separation of the terrestrial Greek territory into floristic regions follows Strid and Tan [44] and the specific biogeographical region names are used. The implementation of the study consists of the following eight steps (Figure 1):

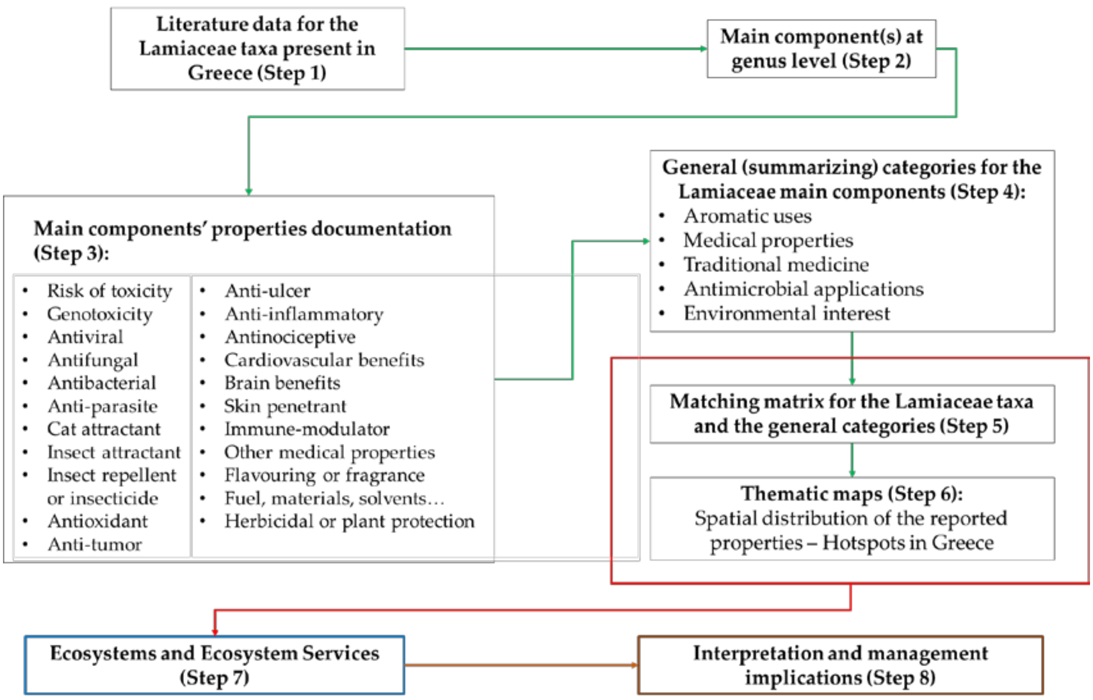

Figure 1. Flowchart of the study.

Step 1: Data on the existing knowledge for each endemic Lamiaceae taxon are collected by using "taxon name" and/or "Lamiaceae + Greece" as key words in the Google Scholar, Science direct, Scopus and Web of Science databases. The goal was to gather all existing literature for each Lamiaceae taxon referring to: (a) the chemical constituents of its essential oils, (b) its medicinal uses, (c) its environmental value, (d) its culinary uses and (e) the last discoveries about its biochemical, potential applications. In addition, the knowledge about the endemic taxa has been completed by data concerning closely related, non-endemic species (e.g., *Lamium garganicum* subsp. *striatum* (Sm.) Hayek, *Satureja montana* subsp. *pisidia* (Wettst.) Šilic, *Teucrium chamaedrys* subsp. *lydium* O. Schwarz). As a result, 741 papers have been assessed, including 356 studies dealing with molecules' properties;

Step 2: The gathered information was filtered on the basis of the main component (e.g., 1.8-cineole, alpha-cadinol, alpha-copaene, alpha-pinene, bêta-caryophyllene, carvacrol, etc.) at the genus level;

Step 3: Main components were assigned to one or more properties (i.e., risk of toxicity, genotoxicity, antiviral, antifungal, antibacterial, anti-parasite, cat attractant, insect attractant, insect repellent or insecticide, antioxidant, anti-tumor, anti-ulcer, anti-inflammatory, antinociceptive, cardiovascular benefits, brain benefits, skin penetrant, immune-modulator, other medical properties, flavoring or fragrance, fuel, materials, solvents, herbicidal or plant protection;

Step 4: Properties identified in Step 3 were assigned under five general categories, i.e., (i) aromatic uses: this category points out the species with known uses as aromatic oils, food, spices or cosmetics; (ii) medical properties: this category refers to plant extracts that have been scientifically proved to possess properties of medical interest (antioxidant, antitumor, antidiabetic, anti-leukemic, immuno-stimulating, etc.), some of them may already be exploited and commercialized for medical purposes (treatments, essential oil, etc.); (iii) traditional medicine: this category includes plants that have been used for a long time by the locals, and have been empirically known for their medical properties; (iv) antimicrobial applications: this category refers to plant extracts presenting antibacterial, antifungal, anti-yeast or antiviral potential applications; and (v) environmental interest: this category includes plants presenting ornamental or landscaping interests, or plants which can have beneficial applications when used or utilized as a living organism (educational value in botanical gardens and protected areas, ecotourism value, habitat indicator, habitat or soil restoration, honey plant, etc.) and/or as a natural extract (insecticidal, herbicidal, etc.);

Step 5: For identifying the properties per taxon, a matching table (matrix) for the main components, the relevant properties and the general categories was drafted for each taxon;

Step 6: Using distribution data for each taxon, thematic maps were prepared focusing on the spatial distribution of the endemic and non-endemic Lamiaceae taxa and of their properties. Gradients patterns and heatmaps are used to distinguish hotspots and data gaps for each map. This analysis includes endemic and non-endemic Lamiaceae taxa of Greece, aiming to compare with the taxa of interest (i.e., endemic);

Step 7: Correspondence to the Common International Classification of Ecosystem Services (CICES ver. 5.1) [45] sections (i.e., Provisioning, Regulating and Maintenance, Cultural) and the relevant codes is also presented and assigned to the relevant categories of the IPEBS [46], Millenium Ecosystem Assessment (MA) [30] and TEEB [47]. Ecosystem types supporting these ES are highlighted and ES bundles regarding the identified ES are depicted in thematic maps;

Step 8: Results interpretation and management implications, suggestions for future actions and support to policy making.

3. Results

3.1. Flora Statistics and Distribution

A list of 414 Lamiaceae taxa, including 111 Greek endemics, has been exported from Dimopoulos et al. [41,42] and the Flora of Greece Web online database [43]. These 111 taxa belong to 88 species, from 19 genera. *Stachys* is the richest in endemics genus with 24 endemic taxa (18 species), followed by *Scutellaria* (13 taxa from 7 species) and *Teucrium* (12 taxa from 11 species). The endemism rates (i.e., count of endemic taxa/total count of taxa) at the family and the genus level in relation to their species and taxa are as follows:

i. Family level: 26.8% (111 out of 414 taxa) when considering the taxa and 34% (88 of the 262 species) when considering the species;
ii. Genus level: *Origanum* is characterized by the highest endemism rate (70%) with 7 endemic species out of 10, followed by *Satureja* (60%), *Nepeta* and *Teucrium* (58%) (Figure 2a). *Nepeta* presents the highest rate with 10 endemic taxa out of 18 (56%), mostly due to the numerous endemic *Nepeta argolica* subspecies, followed by *Origanum* (54%) and *Scutellaria* (46%) (Figure 2b).

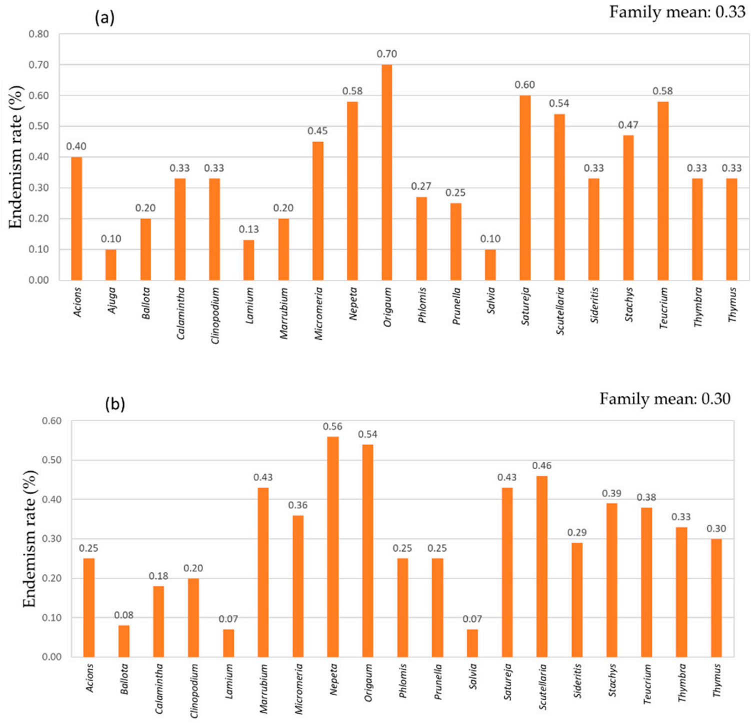

Figure 2. Endemism rates of Lamiaceae genera, at their species (**a**) and taxon (**b**) level.

The distribution patterns of the Lamiaceae in Greece for total taxon and endemic taxon richness, as thematically represented on gradient maps, highlight the following:

a. Areas rich in Lamiaceae (orange to red cells) are located in northern and southern Pindos (NPi, SPi), Stereas Ellas (StE) and Peloponnisos (Pe), North Central Greece (NC) and Kriti (Kr) (Figure 3);
b. Hotspot regions of Lamiaceae endemics are located on the Kriti (Kr) and Karpathos (Kp) islands and in Peloponnisos (Pe), especially in the southeast part of the region; Mt Athos (NE) can also be considered as a local hotspot (Figure 4).

3.2. *Main Components and Properties*

3.2.1. Main Components

For 57 out of the 111 endemic Lamiaceae taxa, the components have been detected from previous studies, testing a total of 134 samples of these taxa (Table 1). When focusing on the major component of each of these 57 taxa, we find that the more frequent one is carvacrol, detected in 12 taxa and especially in *Satureja* with 4 taxa, followed by thymol (6 taxa, including 3 *Satureja* and 2 *Thymus*), alpha-pinene (5 taxa, including 4 *Sideritis* and 1 *Phlomis*) and p-cymene (5 taxa, including 2 *Origanum* and 3 *Thymus*). Other molecules have been also detected and some have only been found as main components for two taxa (six molecules including bêta-elemene, delta-cadinene, linalool, nepetalactone derivatives) or for one taxon (11 molecules including (E)-nerolidol, alpha-copaene, gamma-terpinene and spathulenol, among others). For some taxa, the content of metabolites like iroids, flavonoids or neoclerodanes has been investigated, especially for eight taxa for which these lists are the only available information about their essential oils' composition (including two *Marrubium* taxa). For four other taxa, only one to two compounds have been detected, in order to compare these taxa with others in their own genus. However, the composition of the essential oils for 54 endemic taxa are still unknown and could only be deduced from the composition of similar species belonging to the same genus (e.g., *Acinos*, *Ballota*, *Clinopodium*).

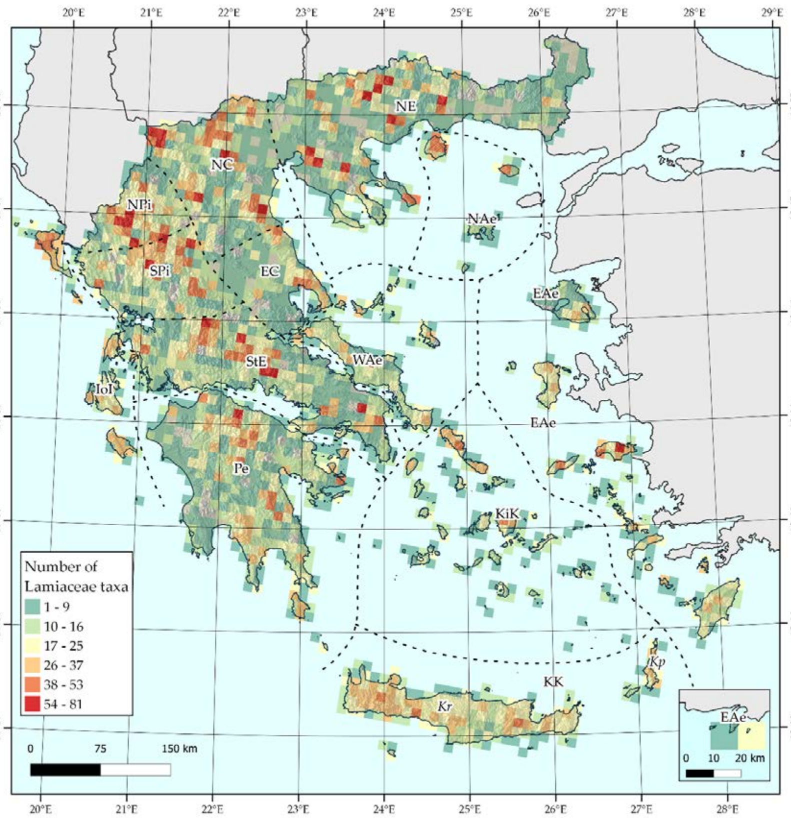

Figure 3. Distribution of the Lamiaceae taxa in Greece (10 × 10 km, EEA reference grid). Dotted lines delineate the floristic regions of Greece [44].

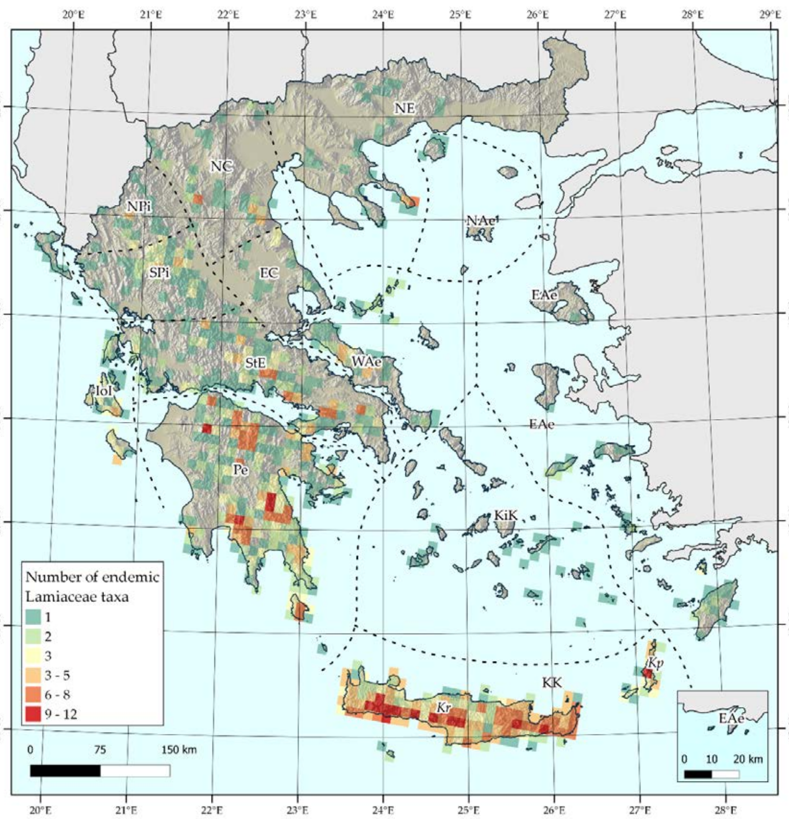

Figure 4. Distribution of the endemic Lamiaceae taxa in Greece (10x10 km, EEA reference grid). Dotted lines delineate the floristic regions of Greece [44].

Table 1. Main components of Greek endemic Lamiaceae, assigned to number of taxa and genus/genera represented. Genera in bold characters represent the genus with most taxa per main component.

Main Components	Number of Taxa	Genus (Genera) Represented
(E)-caryophyllene	4	*Satureja*, ***Stachys***
(E)-nerolidol	1	*Stachys*
1,8-cineole	5	*Nepeta*
Alpha-cadinol	1	*Stachys*
Alpha-copaene	1	*Stachys*
Apha-pinene	5	*Phlomis*, ***Sideritis***
Bêta-caryophyllene	2	*Sideritis, Teucrium*
Bêta-copaene	1	*Sideritis*
Bêta-elemene	2	*Stachys*
Carvacrol	12	*Origanum*, ***Satureja***, *Sideritis, Stachys, Teucrium, Thymbra, Thymus*
Caryophyllene oxide	4	*Nepeta*, ***Stachys***
Delta-cadinene	2	*Stachys*
Gamma-terpinene	1	*Satureja*
Geraniol	1	*Thymus*
Germacrene D	4	*Phlomis*, ***Teucrium***, *Thymus*
Isoabienol	3	***Sideritis***, *Stachys*
Limonene	1	*Stachys*
Linalool	2	*Scutellaria, Thymus*
Nepetalactone derivatives	2	*Nepeta*
p-cymene	5	*Origanum*, ***Thymus***
Piperitenone oxide	1	*Calamintha*
Piperitone oxide	2	*Calamintha*
Spathulenol	1	*Satureja*
Terpinen-4-ol	1	*Origanum*
Thymol	6	*Origanum*, ***Satureja***, ***Thymus***
Viridiflorol	1	*Stachys*
Only flavonoid, iroid, phenolic or neoclerodane contents available	8	***Marrubium***, *Scutellaria*, ***Stachys***, *Teucrium*
Only one or two compounds known	4	*Origanum, Scutellaria, Teucrium, Thymus*
Unknown	54	*Acinos, Ballota, Clinopodium, Lamium, Micromeria, Prunella, Salvia, Scutellaria, ...*

3.2.2. Properties

The review of the existing scientific literature enabled this study to identify noticeable properties for the components (Table 2) of 37 Lamiaceae taxa among the 111 Greek endemics and assign them to general property categories (Tables S1 and S2 of the supplement). In addition, two more types of information enriched the review: (i) some studies suggested properties, without scientific evidence or proof, but considered their traditional use, and (ii) certain properties proved to exist within a species, which have been attributed as suggested properties for closely related subspecies (i.e., the properties suggested by scientists without proven scientific demonstration). In the latter case, for example, *Nepeta argolica* subsp. *dirphya* (Boiss.) Strid & Kit Tan has been documented as antibacterial, which suggests that the endemics *Nepeta argolica* Bory & Chaub. subsp. *argolica* and *Nepeta argolica* subsp. *malacotrichos* (Baden) Strid & Kit Tan could also possess this property. With the inclusion of these different sources, 74 taxa out of the 111 have been assigned to one or several general property categories (66%). At the same time, more than one third of the total number of taxa still has not been studied with regard to their properties; an additional one third has only been proved to possess a single property. Some more documented taxa are suspected to have two properties (24%) or more (12%).

Table 2. Correspondence matrix among components and properties. x = proved property; ? = suspected or weak property; No = property proved to be absent; green cells = most investigated property for that substance.

	Properties																					
Components	**Risk of Toxicity**	**Genotoxicity**	**Antiviral**	**Antifungal**	**Antibacterial**	**Anti-Parasite**	**Cat Attractant**	**Insect Attractant**	**Insect Repellent or Insecticide**	**Antioxidant**	**Anti-Tumor**	**Anti-Ulcer**	**Anti-Inflammatory**	**Antinociceptive**	**Cardiovascular Benefits**	**Brain Benefits**	**Skin Penetrant**	**Immune-Modulator**	**Other Medical Properties**	**Flavouring or Fragrance**	**Fuel, Materials, Solvents**	**Herbicidal or Plant Protection**
(E)-caryophyllene								x	x		No		?	?								
(E)-nerolidol		?		x	x	x		x	x	x	x	x		x			x			x		?
1,8-cineole		No		x	x				x	x	x		x	x	x	x	x		x		x	x
Alpha-cadinol					?	?			x				?						?			
Alpha-copaene		No		?				x		x	x											
Alpha-pinene		No		x	x			x	x	x	x	x	x	x		x			x	x	x	
Beta-caryophyllene		No			x			x	x	x	x	x	x	x	x	x		x	x	x		x
Beta-copaene																						
Beta-elemene				x	?					x	x		x						x			
Carvacrol	?	No	X	x	x	x			x	x	x		x	x	x	x			x		x	x
Caryophyllene oxide	x	No		x	x	x			x	x	x		x	x		x						x
Delta cadinene				?	x				?											x		?
Gamma-terpinene					x					x			x	x							x	
Geraniol	?			x	x			x	x	x	x	x	x		x		x			x	x	
Germacrene D					?			x	x													
Isoabienol					?															x		
Limonene	?			?	x				x	?	x		x	x		x		?	x	x	x	
Linalool					x	x			x	x			x	x	x	x				x		
Nepetalactone derivatives				x	x		x		x					x		x						
p-cymene					x				x	x	?		x	x								
Piperitenone oxide		x	X	x	x	x			x	x	x		x	x	x				x	x		
Piperitone oxide						?			?													
Spathulenol				x	x					x	x		x					x		x		
Terpinen-4-ol				x	x				x		x		x		x				x			
Thymol		No		x	x	x			x	x	?		x						x		x	
Viridiflorol				x	x				x	x			x						x			
Total of x	1	1	2	13	18	6	1	7	18	16	13	4	16	12	7	8	3	2	10	10	7	4
Total of ?	3			3	4	2			2	1	2		2	1				1	1			2
Total of No		7									1											
Total (x, ?, No)	4	9	2	16	22	8	1	7	20	17	16	4	18	13	7	8	3	3	11	10	7	6

Among the 74 taxa documented as of interest, the most recurrent property is the scientifically documented medicinal aspect; the literature review enabled to list 22 taxa as being of interest for human health, and 10 as suspected to be so. Nevertheless, commercial use as a medicinal drug has only been quoted for *Origanum dictamnus* L. Another main property is the antimicrobial aspect, proved to exist in 21 taxa, and suspected in 16 taxa. The more represented antimicrobial taxa belong to the *Sideritis* and *Stachys* genera. The environmental benefit by the Lamiaceae species is also frequently quoted (18 proved, 5 suspected), especially for *Scutellaria* or *Thymus* species, whose extracts can have insecticidal effects, or can be used for ornamental purposes. The aromatic aspect has mostly been quoted but not yet established, explaining the list of 20 suspected taxa. However, based on their culinary or cosmetical uses, 11 Lamiaceae taxa endemic to Greece have been proved to have this property. In addition to these four categories, *Origanum*, *Satureja* and *Sideritis* have been quoted among the seven proved and the six suspected taxa used in traditional medicine.

Gradient Maps

The thematic representation of the spatial distribution of each general property category per endemic taxon is depicted in Figure 5a–e; five gradient maps, one for each general property category, have been drafted, where the different hotspots are visible, according to the presence of endemic plants of interest for each property. The results of the analysis per category are as follows:

i. Aromatic properties: mountainous areas of SW Kriti (KK) are considered as the main hotspot for endemic taxa with aromatic properties, followed by the mountains of southern Peloponnisos (Pe). Secondary hotspots can be considered the areas of the Pindos mountain range (NPi and SPi) and Mt Olimbos (NC) (Figure 5a);
ii. Medical properties: mountainous areas of Greece are pinpointed as hotspots for endemic plants with medical properties. Kriti (KK) is the main hotspot (especially the eastern part of the island), followed by the mountains of Peloponnisos (Pe), Sterea Ellas (StE), southern Pindos (SPi) and Mt Olimbos (NC). Mt Athos (NE) is considered as a local hotspot (Figure 5b);
iii. Antimicrobial properties: all the mountains of Peloponnisos (Pe) are hotspots for the Greek endemic taxa with antimicrobial properties. Kriti (KK) follows, with one or more Greek endemics with antimicrobial properties occurring almost throughout the island. Mountains of Sterea Ellas (StE) are also highlighted as important, alongside the local hotspots of Mt Olimbos (NC) and Mt Athos (NE) (Figure 5c);
iv. Traditional medicine: Mt Olimbos (NC), Mt Parnon (Pe) and Mt Lefka Ori (KK) are the prevailing hotspots; other mountain ranges throughout Greece follow. It should be mentioned that the lack of well documented traditional uses of Greek endemic Lamiaceae in the literature is probably giving a weak signal with regard to the traditional uses of the Greek endemic Lamiaceae and thus biases the result of their spatial representation (Figure 5d);
v. Environmental interest: Mt Taigetos (Pe), Mt Lefka Ori (KK), Mt Vourinos (NC) and the island of Kefallinia (IoI) are the main hotspots. A weak signal is also present for this category, due to the lack of extensive literature sources (Figure 5e).

The cumulative result of the above-mentioned categories is presented in the map of Figure 5f. Most significant hotspots of the co-existing Greek endemic Lamiaceae have been depicted and include Kriti (KK), Peloponnisos (Pe), southern and northern Pindos (SPi and NPi). Local hotspots are present throughout Greece, in the mainland and secondary to the islands, mainly at the Ionian Islands (IoI), and secondary in the Aegean (EAe, NAe) (Symi, Ikaria and Thasos). Mt Olimbos (NC) and Mt Athos (NE) are also pinpointed as cumulative local hotspots.

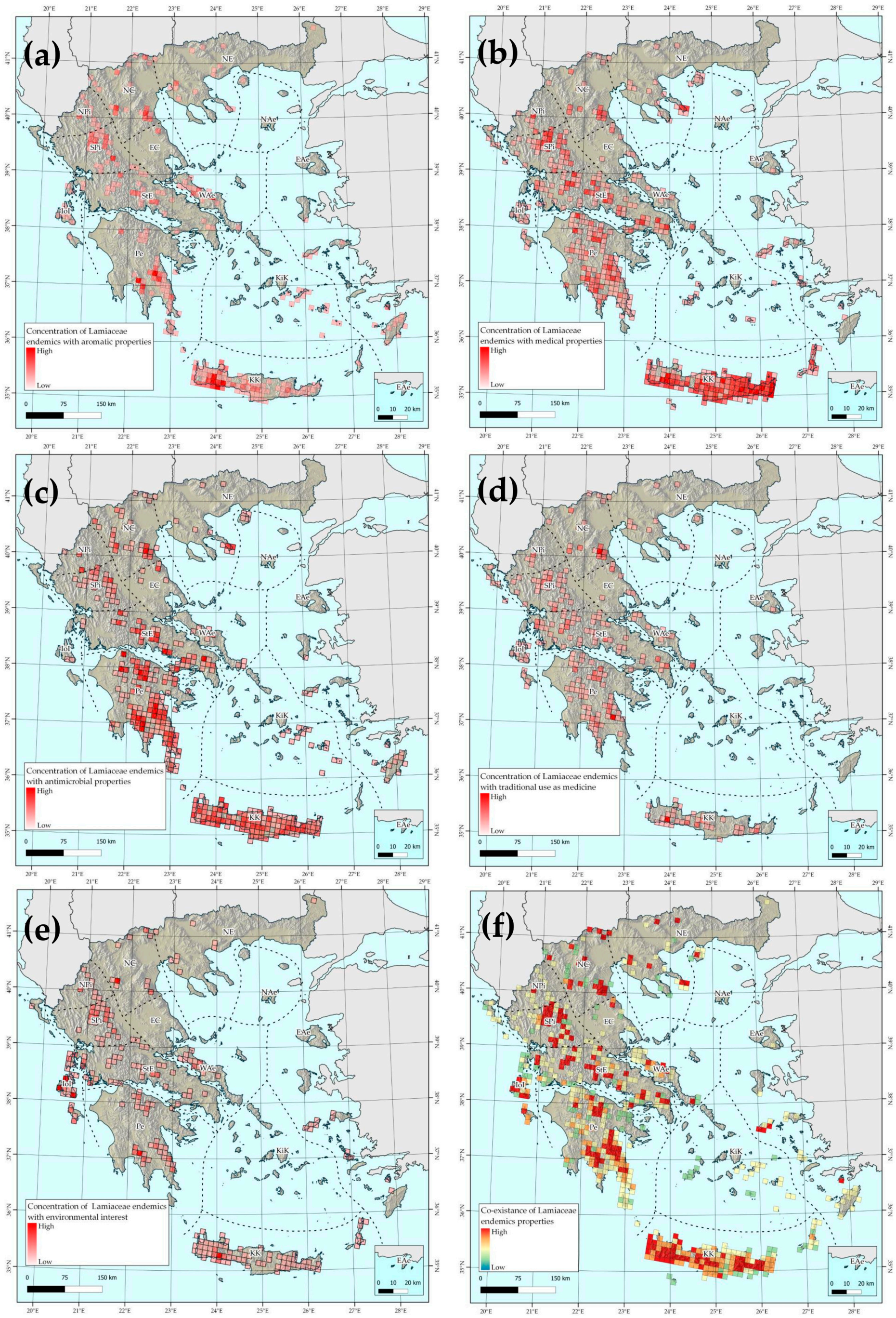

Figure 5. Distribution of the reported properties per endemic taxon using the 10x10 km EEA reference grid; (**a**) aromatic properties, (**b**) medical properties, (**c**) antimicrobial properties, (**d**) traditional medicine, (**e**) environmental interest, (**f**) cumulative representation of the different properties present per cell.

3.2.3. Ecosystems and Ecosystem Services

Habitat Categories and Ecosystem Types

The habitat preferences analysis of the Greek endemic Lamiaceae taxa assigned them to the different habitat categories [41,42] and their correspondence to the relevant MAES level ecosystem types [28] (Table 3) and highlighted the following:

i. The majority of the endemic Lamiaceae (41%, i.e., 45 taxa out of 111) occurs on cliffs, rocks, walls, boulder surfaces and ravines, a habitat category corresponding to the sparsely vegetated land MAES ecosystem type (level 2); 31 of these taxa (28% of the total) are exclusively found in this habitat category;
ii. A total of 31 taxa (28%) occur in xeric Mediterranean phrygana and grasslands (Mediterranean dwarf shrub formations, annual-rich pastures and lowland screes), a habitat category corresponding to the heathland and shrub MAES ecosystem type (level 2); 15 of these taxa (14% of the total) are exclusively found in this habitat category;
iii. A total of 30 taxa (28%) occur in high mountain vegetation (i.e., mountain- and oro-Mediterranean grasslands, screes and rocks, scrub above the tree line), a habitat category corresponding to the grasslands and sparsely vegetated land MAES ecosystem types (level 2); 20 of these taxa (18% of the total) are exclusively found in this habitat category;
iv. A total of 21 taxa (19%) occur in temperate and sub-Mediterranean grasslands, i.e., lowland to montane dry and mesic meadows and pastures, rock outcrops and stony ground, grassy non-ruderal verges and forest edges; these habitats correspond to the grasslands and sparsely vegetated land MAES ecosystem types (level 2); 12 of these taxa (11% of the total) are exclusively found in this habitat category;
v. A total of 13 taxa (12%) are found exclusively in woodlands and scrub, i.e., broadleaved and coniferous forests, riparian and mountain forests and scrubs, hedges and shady woodland margins; these habitats correspond to the woodland and forest MAES ecosystem types (level 2); two of these taxa (2% of the total) are exclusively found in this habitat category;
vi. Finally, two taxa (2%) are found in agricultural and ruderal habitats (fields, gardens and plantations, roadsides and trampled sites, frequently disturbed and pioneer habitats), habitats corresponding to the cropland and urban MAES ecosystem types (level 2); one of these taxa (1% of the total) is exclusively found in this habitat category.

Table 3. Number of Greek endemic Lamiaceae taxa per habitat category and Mapping and Assessment of Ecosystems and their Services (MAES) ecosystem type (level 2). Numbers in the parenthesis indicate number of taxa exclusively present in the corresponding habitat category.

Habitat Category [41,43]	MAES Ecosystem Type (Level 2) [28]	Number of Greek Endemic Lamiaceae Taxa
C: Cliffs, rocks, walls, ravines, boulders	Sparsely vegetated land	45 (31)
G: Temperate and sub-Mediterranean grasslands (lowland to montane dry and mesic meadows and pastures, rock outcrops and stony ground, grassy non-ruderal verges and forest edges)	Grasslands/Sparsely vegetated land	21 (12)
H: High mountain vegetation (mountain- and oro-Mediterranean grasslands, screes and rocks, scrub above the tree line)	Grasslands/Sparsely vegetated land	30 (20)
P: Xeric Mediterranean phrygana and grasslands (Mediterranean dwarf shrub formations, annual-rich pastures and lowland screes)	Heathland and shrubs	31 (15)
R: Agricultural and ruderal habitats (fields, gardens and plantations, roadsides and trampled sites, frequently disturbed and pioneer habitats)	Cropland/Urban	2 (1)
W: Woodlands and scrub (broadleaved and coniferous forest, riparian and mountain forest and scrub, hedges and shady woodland margins)	Woodland and forest	13 (2)

It is evident that sparsely vegetated land hosts most of the Greek endemic Lamiaceae and the majority of these taxa are exclusively present in this ecosystem type (i.e., 31 taxa) or are present in sparsely vegetated land and in grasslands (32 taxa), a total of 63 taxa. This fact pinpoints grasslands as the second richest ecosystem type in Greek endemic Lamiaceae; heathland and shrubs, woodland and forest follow.

Ecosystem Services

Assigning the general (summarizing) categories of the Lamiaceae endemics to the CICES categories and to the relevant ecosystem services categories of the MA and TEEB (Table 4), we present the following:

i. Aromatic uses correspond to (a) two CICES codes of provisioning services, (b) three IPEBS categories, (c) four MA categories and (d) three TEEB categories;
ii. Medical properties correspond to (a) one CICES code of provisioning services, (b) two IPEBS categories, (c) three MA categories and (d) two TEEB categories;
iii. Traditional medicine corresponds to (a) one CICES code of provisioning services and to three CICES codes of cultural services, (b) three IPEBS categories, (c) seven MA categories and (d) five TEEB categories;
iv. Antimicrobial applications correspond to (a) one CICES code of provisioning services, (b) one IPBES category, (c) three MA categories and (d) two TEEB categories;
v. Environmental interest corresponds to (a) three CICES codes for regulating and maintenance services and to four CICES codes of cultural services, (b) seven IPBES categories, (c) fourMA categories and (d) one TEEB category.

The localization of the areas of Greece where the highest numbers of endemic Lamiaceae have been recorded, i.e., different taxa records and different records from the same taxon, set the scientific basis for the ecosystem services hotspot areas and the ecosystem services cumulative importance (ecosystem services bundles) documentation. The results of this analysis are presented in Figure 6, combined with the delineated Natura 2000 sites to identify possible conservation needs and protection status. We pinpoint the following:

i. The island of Kriti is the main hotspot and especially its mountainous regions and mountain summits;
ii. The mountain summits of the southern Peloponnisos Peninsula (especially Mt Taigetos and Mt Parnon), Evvoia Island (Mt Dirfis), Mt Olimbos and Mt Athos (Chalkidiki peninsula) are assessed as local hotspots. Secondary local hotspots have been assessed on the mountains of northern Peloponnisos (Mt Chelmos, Mt Killini), Sterea Ellas (Mt Parnis, Mt Parnassos, Mt Giona) and of northern and southern Pindos (Mt Timfi, Mt Peristeri, Mt Tzoumerka);
iii. The extent of the Natura 2000 network in Greece covers all identified ecosystem services supply, or potential supply hotspots, as well as areas of lower importance based on the endemic Lamiaceae records.

Table 4. Correspondence of the general (summarizing) categories of the Lamiaceae Greek endemics to the CICES categories and the relevant ecosystem services categories of IPBES, MA and TEEB.

General Categories of Main Components for Lamiaceae Greek Endemics	CICES Section			IPBES Name (Code)	MA	TEEB
	Provisioning (Codes)	Regulating and Maintenance (Codes)	Cultural (Codes)			
Aromatic uses	1.1.5.1;1.1.5.2	-	-	12; 13; 14	Food; fiber, timber; ornamental; biochemical	Food; raw materials; medicinal resources
Medical properties	1.1.5.2	-	-	13; 14	Fiber, timber; ornamental; biochemical	Raw materials; medicinal resources
Traditional medicine	1.1.5.2	-	3.1.2.1;3.1.2.2; 3.1.2.3	6; 13; 15	Fiber, timber; ornamental; biochemical; Knowledge systems and educational values; cultural diversity; aesthetic values; spiritual and religious values	Raw materials; medicinal resources; information and cognitive development; inspiration for culture, art and design; aesthetic information
Antimicrobial applications	1.1.5.2	-	-	14	Fiber, timber; ornamental; biochemical	Raw materials; medicinal resources
Environmental interest	-	2.2.2.1; 2.2.2.3; 2.2.3.1;	3.1.2.1;3.1.2.2; 3.1.2.4; 3.2.1.3	1; 2; 6; 10; 13; 15; 17	Pest regulation; knowledge systems and educational values; cultural diversity; aesthetic values	Biological control

CICES class codes and names: 1.1.5.1—wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition; 1.1.5.2—fibers and other materials from wild plants for direct use or processing (excluding genetic materials); 2.2.2.1—pollination (or “gamete” dispersal in a marine context); 2.2.3.1—pest control (including invasive species); 3.1.2.1—characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge; 3.2.1.3—Elements of living systems used for entertainment or representation. IPEBS codes and names: 1—habitat creation and maintenance; 2—pollination and dispersal of seeds and other propagules; 6—regulation of freshwater quantity, location and timing; 10—regulation of organisms detrimental to humans; 12—food and feed; 13—materials and assistance; 14—medicinal, biochemical and genetic resources; 15—learning and inspiration; 17—supporting identities.

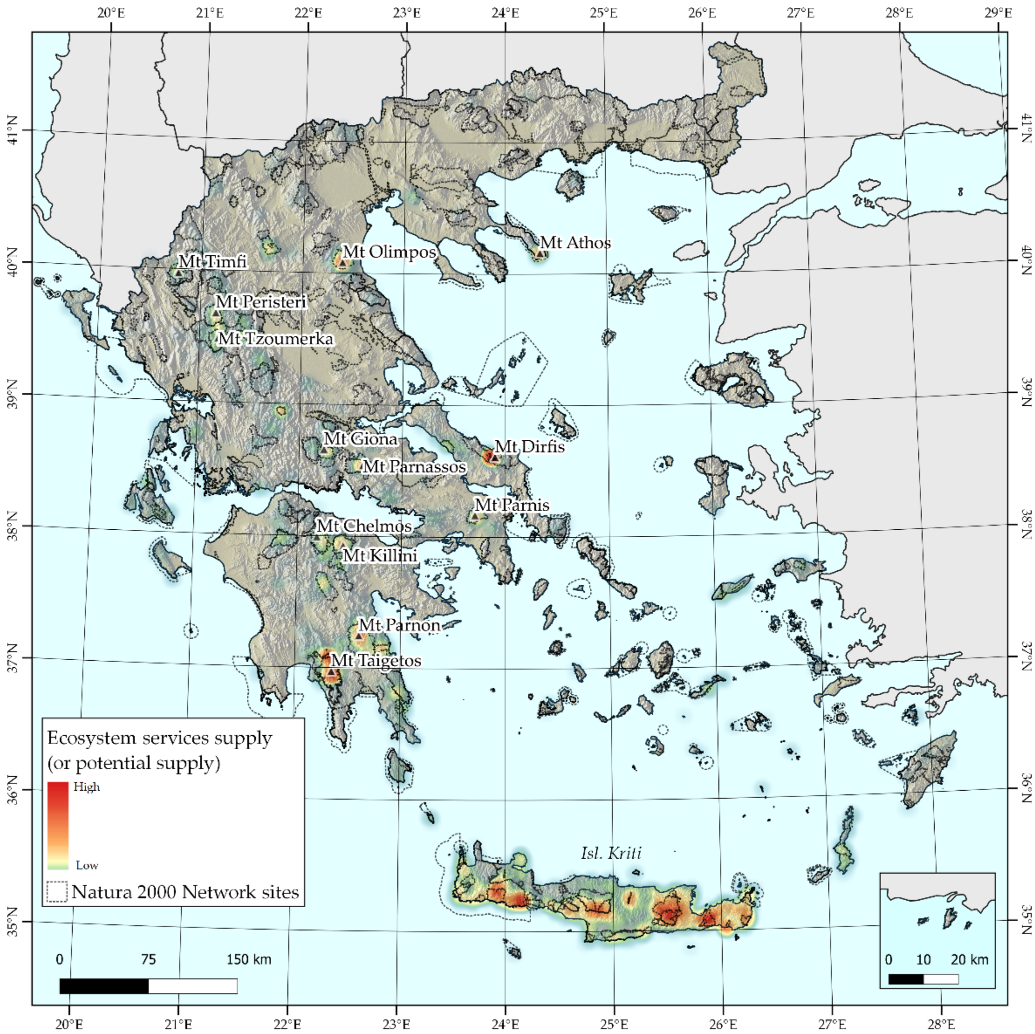

Figure 6. Ecosystem services hotspots in Greece, based on the recordings of the Greek endemic Lamiaceae. Natura 2000 sites in Greece are also depicted.

4. Discussion

Endemic taxa of Lamiaceae are distributed among 19 genera out of the 35 present in Greece. The most endemic taxon-rich genera are *Stachys*, *Scutellaria* and *Teucrium*, representing 45% of the endemic taxa of Lamiaceae, as well as 30% of the total Lamiaceae taxa in Greece. At the taxon (species and subspecies) and the species level, other genera such as *Nepeta*, *Origanum* and *Satureja* contain less taxa but a higher proportion of endemics. Thus, two groups of genera could be highlighted: (a) genera with a high number of endemics and (b) genera with a high proportion of endemics. These two groups could be used for plant conservation purposes, but also for management of commercial exploitation. More precisely, the main focus for the first group could target variations in the components proportions in each genus, whereas the second group would tend to offer more new active compounds or properties.

4.1. Properties and Components

Two thirds of the endemic taxa in Lamiaceae have no proven human-interest applications, according to the current state of knowledge. Nevertheless, other taxa included in the same genus or species, endemic or not, have already been investigated and documented as having properties of interest. As an example, from the review data extracted, *Teucrium montanum* subsp. *helianthemoides* (Adamović) Baden is a yet uninvestigated subspecies of *Teucrium montanum* L., whereas the latter has been quoted as having antifungal and antioxidant properties, and is already used in traditional medicine and for culinary purposes [48–50]. Moreover, for the currently documented species, studies have focused on certain properties, whereas others, not yet explored, might also be of interest. Medicinal and antimicrobial uses are the most recurrent properties studied. These properties can be proved by experiments led in a restricted time in the laboratory. The environmental aspects dealing with habitat restoration or indicators are rarely considered, and the social aspects as traditional remedies or garden plants are only approached through ethnobotany and ethnopharmacology.

The properties of the endemic Lamiaceae taxa are due to the presence of one or a combination of essential oil components. In order to obtain a better understanding of the properties and active compounds that the taxa could provide, a review of the molecules was necessary. Some already well-known essential oil components, such as carvacrol and thymol, as their precursors gamma-terpinene and p-cymene, were expected to be found and are part of many of the investigated species, as main or secondary compounds. However, other species proved to be rich in more uncommon components, e.g., *Thymus holosericeus* Čelak. for geraniol, *Stachys spruneri* Boiss. for limonene and *Calamintha cretica* (L.) Lam. for piperitenone oxide. This information could be of great importance to identify naturally provided sources of these compounds. Indeed, the three molecules previously quoted as examples have all been targeted as presenting positive attributes, i.e., geraniol could have applications in insect repellency and for anti-tumor treatments [51–54], limonene has significative antinociceptive effects [55] and piperitenone oxide is investigated for insecticidal uses and cardiovascular protection [56–58]. However, research gaps are still present, since each component has not yet been studied (e.g., beta-copaene, isoabienol), and some kinds of properties are still to be investigated for all the components (e.g., antiviral, immuno-stimulant, cardiovascular protection). It should be mentioned that the widespread molecules like carvacrol or caryophyllene oxide, which have already been deeply examined, have demonstrated efficiency in a wide range of applications [59,60].

4.2. Limitations of the Study

This study identified two main data gaps in the knowledge of the properties of the endemic Lamiaceae: (i) the first one is geographical and refers to the lack of surveys in some areas of Greece (shown as without-color patches on the thematic maps), either due to low biodiversity in these areas, or due to the better accessibility or reputation of other areas; (ii) the second one concerns the focus of the studies; knowledge is missing on the chemical composition and on the existence of properties in some taxa. In particular, the data gap concerns the choice of the studied aspects, i.e., some properties are more prone to be investigated than others, while other properties may still be discovered as they have been found in other taxa of the same genus. Certain knowledge gaps are also apparent at the links between the molecules and the properties, especially when more than one component needs to be combined to be more efficient. Subsequently, this demonstrates the importance of conducting further research to explore more about the endemic taxa, their specific distributions and their uses.

Other limitations include the following: (a) some species that are found in different locations may have different chemical compositions and properties depending on specific ecological conditions (e.g., altitude, soil, climate, season) [61–63], (b) some non-endemic taxa of particular genera have been proved to contain major compounds, which have not yet been detected in endemic ones, e.g., hexadecanoic acid in the *Scutellaria* genus and bêta-thujone in *Satureja* species [64,65], (c) the clusters produced by the spatial analysis are based on the restrictive hypothesis that the attributes of the taxa are the same at all times and all places. Future steps for improving the method used in this study could take into account more precise spatial and temporal data, especially since essential oils compositions have been proven to vary depending on the season [66–68]. Still, having a perfect description of the essential oils would necessitate handling too much data at once, e.g., plant organ considered, plant development stage, interactions with predators and with the ecosystem and modifications due to cultivation, which provide more limitations for a holistic approach and thus the segmentation of the analysis to specific-oriented parts.

4.3. Ecosystem Services and Management Implications

The Greek endemic taxa of Lamiaceae as ecosystem services providers are significant, since they can (a) support traditional harvesting methods and trade, and (b) act as genetic resources for reproductive materials of cultivated plants. Moreover, Heinrich [69] proposed that these results support guidance on modern and efficient research for bioactive components. Additionally, data collected during herbal market surveys, e.g., [5,70,71], regarding the origin and collection sites of each plant taxon can provide important ecological (e.g., population sites and size) and economic information (e.g., contribution to local economy). By this, management and policy decisions can be supported for the sustainable use of wild resources, as well as for the development of the cultivation of aromatic and medicinal plants, towards the protection of wild populations from overexploitation [5]. The need to protect natural populations has become much more urgent in recent years, since the overexploitation or even the fatal damage of aromatic plants (i.e., by inappropriate harvesting methods), especially the herbaceous ones, mainly for trade, is repeatedly reported by the state authorities (Forest Service). Overharvesting and lack of enforcement even in protected areas are serious problems for many targeted endemic species, e.g., *Origanum dictamnus* L. in Kriti [5] and the "mountain teas" (including *Sideritis* spp.) on the mainland.

As Solomou et al. [4] concluded, medicinal and aromatic plants have a crucial role in the utilization of the natural wealth and biodiversity conservation in the country; moreover, due to the selective and multifaceted biological activity of essential oils, considerable potential on the use of aromatic plants for novel applications in sustainable agriculture exists, valuable uses are possible and medicinal and aromatic plant diversity represents attainable new, environmentally and economically sustainable opportunities for agricultural areas.

The results revealed that all known endemic hotspots for Lamiaceae taxa in Greece are included in the Natura 2000 network. However, only four of the endemic plants of Lamiaceae (*Micromeria taygetea* P.H. Davis, *Nepeta argolica* subsp. *dirphya* (Boiss.) Strid & Kit Tan, *Nepeta sphaciotica* P.H. Davis, *Origanum dictamus* L.) are included in Annex II of the EU Habitats Directive (Dir. 92/43/EE) and monitored for their conservation status. Aromatic plants and especially the local endemics should be considered as an important and unique part of the country's natural capital; thus, quantitative data for the ecosystem services supply (or potential supply) by the plant species (e.g., of components, properties, material, spiritual, aesthetic importance) are needed to develop natural capital accounts and integrate them into local, regional and national decisions and policy-making processes.

5. Conclusions

The Lamiaceae family is represented in Greece by 111 endemic taxa. Most of them are located in southern Greece and Kriti. Many endemic taxa have not been studied in depth. However, according to existing documentation and the non-endemic plants assigned to the same genera, numerous and various properties are to be expected, ranging from medicinal applications to ethnobotanical and environmental interest. Moreover, their essential oils are rich in compounds that could be extracted for pharmaceutical uses, such as antimicrobials or insect repellents. From the ecosystem services point of view, the potential benefits of the endemic Lamiaceae are documented, including as molecule or other chemical properties providers. Additionally, this study also points out patterns of the endemics' properties in the biodiversity hotspot of Kriti. This information could be useful to concentrate measures for the sustainable exploitation of plants occurring in zones of special interest, but also to improve species and ecosystem-based conservation management.

Supplementary Materials: The following are available online at http://www.mdpi.com/1999-4907/11/6/661/s1, Table S1: Properties and components of the Greek endemic Lamiaceae; Table S2: Components correspondence to the general properties' categories.

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