

Article

An Integrated GIS-Based Approach to Biotope Identification and Mapping: A Case Study of Çınarcık District, Türkiye

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Abstract

Biotope mapping provides an essential spatial framework for biodiversity conservation, ecosystem management, and sustainable landscape planning. However, a standardized and transferable GIS-based methodological framework for biotope identification and mapping is still lacking in Türkiye, limiting the systematic integration of biodiversity considerations into spatial planning processes. This study develops an integrated GIS-based biotope mapping framework for Çınarcık District, Yalova Province, Türkiye, integrating Digital Elevation Model (DEM), CORINE Land Cover 2018, Forest Management Plans, stand characteristics, vegetation, floristic, and hydrological data through spatial analyses. Additionally, 30 national and 15 international studies were systematically reviewed to identify the common indicators, data sources, and methodological components used in biotope mapping and to establish the proposed GIS-based framework. The proposed approach identified four main biotope groups (forest, aquatic, agricultural, and urban). Based on ecological similarity and growing environment characteristics, 12 sub-biotope types were identified within the forest biotopes. Forest biotopes were the dominant ecological units, mainly characterized by broadleaved communities dominated by *Fagus orientalis*, *Castanea sativa*, *Tilia tomentosa*, and *Quercus petraea*. A total of 72 forest stand types were identified, with *Fagus orientalis*-dominated forests in plateau environments representing the largest sub-biotope type (36.40%). The proposed framework provides a repeatable and transferable, inventory-based methodology that can serve as a preliminary decision-support tool for biodiversity assessment, conservation planning, and sustainable landscape management in forested landscapes with similar ecological characteristics, pending future field-based validation.

Keywords: biotope mapping; biodiversity; geographic information systems (GIS); forest ecosystems; habitat classification; landscape ecology; stand structure; vegetation analysis; CORINE land cover; Türkiye



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1. Introduction

Biotopes are homogeneous habitats characterized by specific environmental conditions where plant and animal communities coexist [1]. The identification and mapping of biotopes represent an important planning tool for maintaining ecological processes, conserving biodiversity, and ensuring the effective management of natural resources. Biotope maps provide a scientific basis for determining conservation priorities, guiding

land-use decisions, and planning ecological networks by revealing the spatial distribution of habitats [2].

The biotope mapping approach was initially developed and applied in natural areas and urban ecosystems, particularly in Germany, and has subsequently become an important method in landscape planning, nature conservation, and biodiversity monitoring [3,4]. While early studies primarily relied on field observations, habitat characteristics, and vegetation surveys, contemporary biotope mapping approaches increasingly integrate Geographic Information Systems (GIS), remote sensing, Digital Elevation Models (DEMs), land-cover datasets, forest management plans, flora and vegetation analyses, and spatial evaluation techniques for the identification and classification of biotopes.

Despite these methodological developments, biotope mapping approaches differ considerably among regions due to variations in ecological characteristics, data availability, and classification criteria. In Türkiye, although several biotope identification and mapping studies have been conducted in different ecological regions, these studies generally focus on specific case areas and use different indicators, datasets, and classification schemes. Consequently, a common methodological framework that integrates the frequently used indicators and data sources for biotope mapping in Türkiye has not yet been established.

To address this research gap, this study reviewed comprehensive national biotope identification and mapping studies conducted in Türkiye, together with selected international studies representing the methodological development of biotope mapping approaches. The common indicators and methodological components identified through this comparative evaluation were synthesized and used to develop a GIS-based integrated biotope mapping framework.

The Çınarcık district, selected as the study area, represents one of the important biodiversity areas of the Marmara Region and exhibits a heterogeneous landscape structure composed of forest, coastal, aquatic, agricultural, and urban ecosystems. Approximately 60% of the district area consists of forest and agricultural lands, and its location within the transition zone between the Mediterranean and Euro-Siberian phytogeographical regions contributes to its high floristic diversity. The study area's high habitat heterogeneity, comprising forest, coastal, agricultural, and aquatic ecosystems within a relatively small administrative unit, makes it a representative model for biodiversity-rich coastal-forest landscapes in Türkiye that are increasingly exposed to settlement and tourism-driven land-use pressure.

This study is based on the hypothesis that biotopes can be identified in a more detailed and ecologically meaningful manner by integrating land-cover characteristics with physiographic conditions, forest stand structure, vegetation composition, floristic properties, and hydrological components. Accordingly, the aim of this study is to develop and apply a GIS-based integrated biotope mapping approach for Çınarcık District by combining natural and anthropogenic environmental components, identifying main and sub-biotope types, and producing a spatial biotope inventory.

Building on this approach, two interrelated objectives are pursued: (i) at the theoretical level, to develop a systematic, transferable methodological framework for biotope identification by synthesizing indicators commonly used in national and international literature; and (ii) at the applied level, to identify and map the main and sub-biotope types of Çınarcık District, thereby producing a spatial biotope inventory that can support local conservation priorities and sustainable land-use decision-making. Accordingly, this study addresses the following research question: how can commonly used biotope indicators identified from national and international literature be integrated into a transferable, GIS-based framework for biotope identification in ecologically heterogeneous, Mediterranean-transition landscapes?

2. Materials and Methods

2.1. Study Area

The study area is located within the administrative boundaries of Çınarcık district of Yalova Province, Türkiye, and was evaluated ecologically within the boundaries of the Çınarcık Forest Management Chief Directorate. The area is situated on the Armutlu Peninsula in the southeastern part of the Marmara Region and represents a suitable case study area for biotope mapping due to its high floristic diversity, heterogeneous topographic structure, and the coexistence of forest, coastal, agricultural, aquatic, and settlement ecosystems.

The study area extends between $29^{\circ}12'40''$ – $29^{\circ}18'50''$ E and $40^{\circ}37'13''$ – $40^{\circ}39'55''$ N and covers Çınarcık district of Yalova Province, Türkiye. The district is located on the Armutlu Peninsula, which represents the western extension of the North Anatolian Mountains. The area is bordered by the Marmara Sea to the north and has elevations ranging from approximately 30 m near the coastal zone to higher mountainous areas inland [5]. The district covers an area of approximately 174 km² and has a population of 38,600 [6]. The geographical location of the study area is presented in Figure 1.



Figure 1. Location of the study area.

The climate of the study area represents a transition between Mediterranean and Black Sea climatic characteristics, with warm and relatively dry summers and long, cool winters. Annual temperatures generally range between 3 °C and 30 °C, with August being the warmest month (mean maximum: 29 °C; mean minimum: 20 °C) and January the coldest month (mean maximum: 9 °C; mean minimum: 4 °C). Annual precipitation reaches its highest level in December (72 mm) and its lowest level in July (15 mm) [7]. These climatic conditions, together with the heterogeneous topography of the region, contribute to the formation of diverse ecological conditions and habitat types.

The topography of the district is characterized by a mountainous structure associated with the Armutlu Peninsula. Approximately 70% of the area consists of mountainous terrain, while coastal plains, valleys, and low-elevation areas between 0 and 100 m occupy approximately 58% of the district landscape [8]. The coexistence of different elevation zones, slope conditions, and landforms provides environmental gradients that influence vegetation structure, habitat distribution, and biotope diversity (Figure 2).

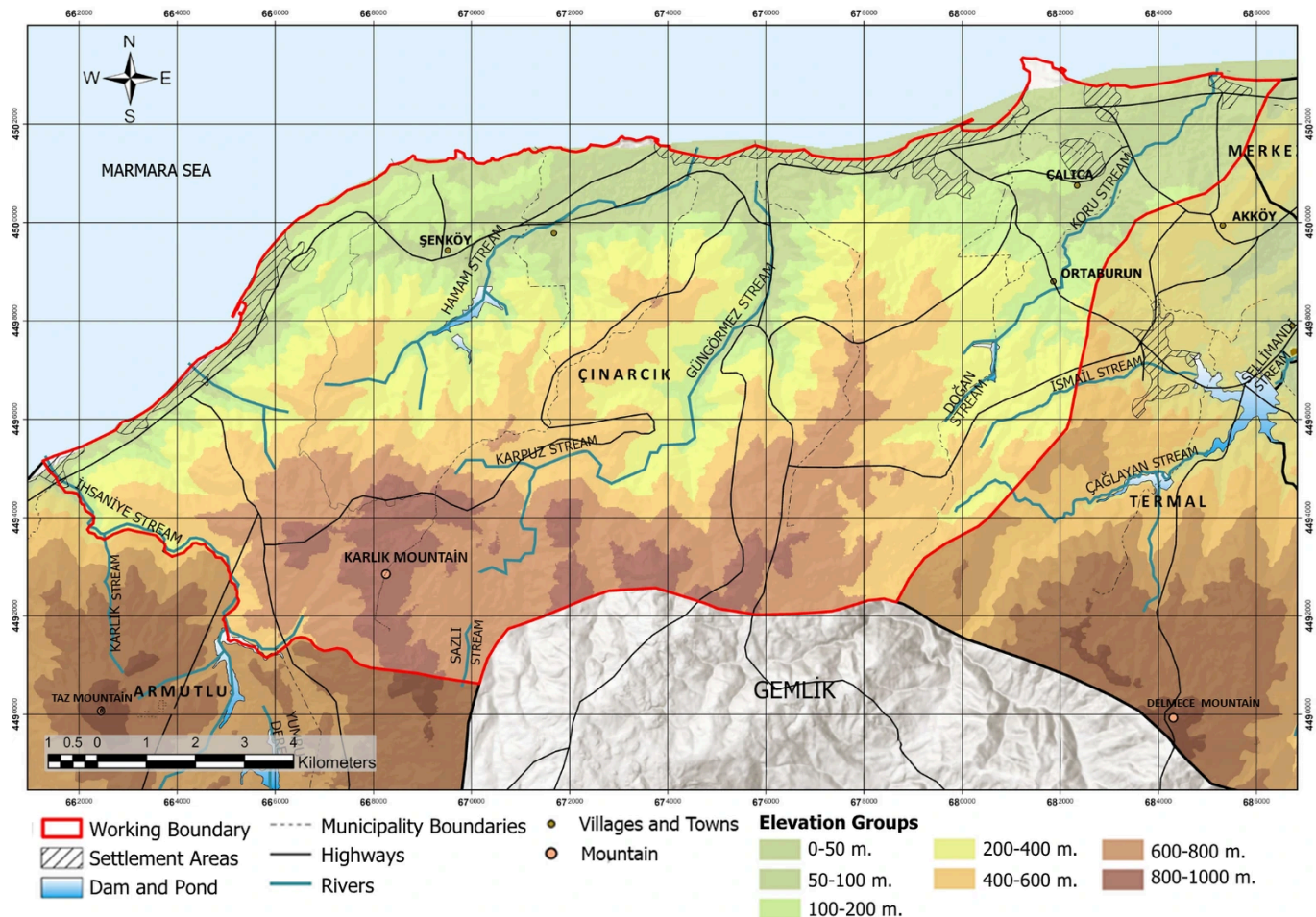


Figure 2. Physiography of Çınarcık District (WGS 1984 UTM Zone 35N).

Çınarcık District was selected as the study area due to its heterogeneous landscape structure encompassing forest, coastal, agricultural, and settlement areas, its location within a floristically rich transitional phytogeographical zone, and the absence of prior systematic biotope mapping studies in the district. The forest inventory data used in this study were derived from 561 sampling plots systematically distributed across a regular 300×300 m grid covering the entire forested area of the planning unit, ensuring spatially representative coverage of the district's forest ecosystems.

2.2. Data Sources

Multiple spatial datasets related to land cover, topography, hydrology, forest structure, flora, vegetation, and settlement areas were used for the identification and spatial mapping of biotopes. These datasets were selected to enable an integrated assessment of the physical environmental characteristics, habitat structure, vegetation composition, and anthropogenic influences defining the study area. The data sources, dataset characteristics, and their specific roles in the biotope identification process are summarized in Table 1. All spatial datasets were accessed between January and October 2025, with the exception of the Forest

Management Plan (2017) and the historical floristic survey (1994), which represent the most recent officially available sources for these respective data types.

Table 1. Data sources used in the study and their roles in biotope identification and mapping.

Dataset	Data Source	Dataset Type	Role in the Analysis
CORINE Land Cover	Copernicus Land Monitoring Service [9]	Vector/Raster	Identification of major land-cover classes and preliminary classification of forest, agricultural, aquatic, and urban biotopes.
Digital Elevation Model (DEM)	Geographic Information Systems [10]	Raster (30 m)	Derivation of elevation, slope, aspect, and physiographic units (plateau, valley, coastal plain, mountainous areas).
Forest Management Plan	Çınarcık Forest Sub-District Directorate [11]	Vector	Identification of stand types, dominant woody species, forest functions, ecological site conditions, and forest biotope classification based on systematic forest inventory.
Topographic Maps & Orthophoto	General Directorate of Mapping [12]	Vector/Raster	Verification of spatial boundaries, geomorphological features, and land-use details.
Flora Data	TÜBİVES, İnan [13,14]	Species Database	Characterization of floristic composition, endemic taxa, habitat affinities, and support for sub-biotope classification.
Hydrographic Network	General Directorate of Mapping [12]	Vector	Identification of streams, drainage systems, wetlands, and aquatic/riparian biotopes.
Settlement & Urban Green Areas	Copernicus Land Monitoring Service [9]	Vector/Raster	Identification of urban biotopes, built-up surfaces, and anthropogenic habitat structures.
Agricultural Land Data	Copernicus Land Monitoring Service [9]	Vector/Raster	Classification of agricultural biotopes, arable land, and cultivation patterns.

The integration of these complementary datasets enabled the simultaneous evaluation of land cover, physiographic conditions, floristic and vegetation characteristics, forest stand structure, hydrological conditions, and habitat attributes, thereby providing the spatial foundation for the subsequent biotope classification and mapping procedures.

The datasets employed in this study originate from official governmental and institutional sources, including CORINE Land Cover (Copernicus Land Monitoring Service), the General Directorate of Forestry (Forest Management Plan), the General Directorate of Mapping, and the Turkish Plants Data Service (TÜBİVES). These sources are systematically produced, regularly updated, and subject to institutional quality control procedures, and they are widely employed in peer-reviewed biotope and habitat mapping research, as confirmed by their frequent use across the majority of the 30 national and 15 international studies reviewed in this paper (Tables 2 and 3). This widespread adoption in the scientific literature supports the scientific validity, reliability, and applicability of the data sources used in the present study.

2.3. Establishment of the GIS Database

All spatial datasets used in the study were integrated within a Geographic Information System (GIS) environment to construct a multi-layered database for biotope identification and mapping analyses. Data layers obtained from various institutions and sources were

first harmonized in terms of their coordinate reference systems. All spatial data were projected into the WGS 1984 UTM Zone 35N coordinate system and standardized at a 1:25,000 scale to match the analysis resolution of the study area.

Within the GIS database, layers were created for land cover, topography, geology, hydrology, forest stand structure, flora, settlement areas, and agricultural land uses. The vector and raster datasets were processed using ArcGIS Pro 3.2.2 software (Esri Inc., Redlands, CA, USA), where data cleaning, digitization, reclassification, buffer analysis, and overlay analysis procedures were conducted.

Following the spatial harmonization of the data layers, an integrated GIS database comprising both natural and anthropogenic components for biotope analysis was established. This database provided the spatial foundation for all subsequent biotope identification, classification, and mapping procedures.

2.4. Establishment of the Biotope Mapping Framework

The theoretical development and methodological components of the biotope mapping approach were initially evaluated based on the international literature. The review of international studies indicates that the concept of biotope, particularly in Central European countries, emerged as a tool for nature conservation, landscape ecology, and urban ecological planning. In early biotope mapping studies, field observations, habitat types, and vegetation characteristics were used as the primary determinants; whereas in later periods, Geographic Information Systems (GIS), land cover data, remote sensing, digital elevation models, and spatial analysis techniques were integrated into these approaches [3,4].

Current international approaches emphasize that biotopes should not be defined solely based on biological components, but through the integrated assessment of various environmental variables, including land cover, land use, topographic characteristics, hydrological structure, habitat continuity, and spatial relationships. Ecosystem and habitat mapping approaches developed in Europe demonstrate the combined use of CORINE land cover data, EUNIS habitat classification, and GIS-based spatial analyses [15]. Similarly, recent studies indicate that remote sensing, multi-source spatial datasets, and integrated analytical approaches are increasingly applied in biotope/habitat mapping studies [16]. To reveal how the main methodological components identified in the international literature are applied under different geographical conditions, selected biotope/habitat mapping studies were comparatively evaluated (Table 2).

Table 2. Comparison of representative international biotope and habitat mapping studies based on the data sources and methodological components used.

Reference	Country	Data Sources and Methodological Components									
		E	S	A	H	V	F	LC	RS	GIS	FO
[3]	Germany	-	-	-	-	✓	-	✓	-	✓	✓
[17]	Germany	✓	✓	✓	✓	✓	✓	✓	✓	-	✓
[18]	Germany	-	-	-	-	✓	✓	✓	-	✓	✓
[19]	Germany	-	-	-	-	-	✓	✓	-	-	✓
[4]	Sweden	✓	✓	-	-	✓	-	✓	-	✓	✓
[20]	Germany	-	-	-	-	✓	✓	✓	-	✓	✓
[21]	New Zealand	✓	✓	✓	✓	✓	✓	✓	-	✓	✓
[22]	New Zealand	✓	✓	✓	✓	✓	✓	✓	-	✓	✓
[23]	UK	-	-	-	✓	✓	-	✓	-	✓	-
[24]	Sweden	-	-	-	-	✓	✓	✓	✓	✓	✓
[25]	Poland	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
[26]	Europe	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 2. Cont.

Reference	Country	Data Sources and Methodological Components									
		E	S	A	H	V	F	LC	RS	GIS	FO
[16]	China	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
[27]	Italy	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
[28]	China	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Abbreviations: E, Elevation; S, Slope; A, Aspect; H, Hydrology; V, Vegetation; F, Forest; LC, Land Cover; RS, Remote Sensing; GIS, Geographic Information System; FO, Field Observations.

Table 3. Comparison of indicators, data sources, and methods used in 30 biotope mapping studies in Türkiye.

No.	E	S	A	DTM	DEM	H	BP	G	GM	GC	ME	S	SS	F	V	EN	FA	FP	C	LC	MP	CO	RS	GIS	BB	NS	LR	KF	BI	FO
[29]	✓	✓	✓	-	-	✓	-	✓	-	-	-	✓	-	✓	✓	-	-	✓	✓	-	-	-	✓	✓	-	-	-	-	-	✓
[30]	✓	✓	✓	-	-	✓	-	✓	-	-	-	✓	-	✓	✓	-	-	✓	✓	✓	-	-	✓	✓	✓	-	-	-	-	✓
[31]	✓	-	✓	-	✓	✓	-	-	-	-	-	-	-	✓	✓	-	✓	✓	✓	-	-	-	-	-	-	-	-	-	-	-
[32]	✓	-	-	-	✓	✓	-	✓	✓	-	✓	✓	-	✓	✓	-	✓	✓	✓	✓	✓	-	✓	✓	-	✓	-	-	-	✓
[33]	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-	✓	✓	-	-	-	-	✓	-	-	✓	✓	-	-	-	-	✓	✓
[34]	-	✓	-	✓	-	✓	-	✓	-	-	✓	✓	-	✓	✓	-	-	✓	-	✓	-	-	-	✓	✓	-	-	-	-	✓
[35]	✓	✓	✓	✓	-	✓	-	✓	✓	-	✓	✓	-	✓	✓	-	✓	✓	✓	✓	✓	✓	-	✓	✓	-	-	-	-	✓
[36]	✓	✓	✓	-	✓	✓	-	✓	✓	-	-	-	-	✓	✓	-	-	✓	✓	-	-	-	✓	✓	✓	✓	-	-	✓	✓
[37]	✓	✓	✓	✓	-	-	-	✓	✓	-	-	✓	-	-	✓	-	✓	✓	✓	✓	✓	-	✓	✓	-	-	-	-	-	✓
[38]	✓	✓	✓	-	-	✓	-	✓	✓	-	✓	✓	-	-	✓	-	✓	-	✓	✓	✓	✓	✓	✓	-	-	-	-	-	✓
[39]	✓	✓	✓	-	-	-	-	✓	✓	-	-	✓	-	-	✓	-	-	-	✓	-	-	-	✓	✓	✓	-	-	-	-	✓
[40]	✓	✓	-	✓	-	-	-	-	-	-	-	✓	-	✓	✓	-	-	-	✓	✓	✓	-	✓	✓	-	-	-	-	-	✓
[41]	✓	✓	✓	-	-	✓	-	-	-	-	-	✓	-	✓	✓	✓	✓	-	✓	✓	-	✓	-	✓	-	-	-	-	✓	✓
[42]	✓	✓	✓	✓	✓	✓	-	✓	✓	-	✓	✓	-	✓	✓	✓	-	✓	✓	✓	✓	-	-	✓	✓	-	-	-	✓	✓
[43]	-	-	-	-	-	-	-	-	-	-	-	✓	-	-	✓	-	-	✓	-	✓	-	-	-	✓	-	-	-	-	-	✓
[44]	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	✓	✓	✓	-	✓	✓	-	✓	-	✓	-	-	-	-	-	✓
[45]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	-	-	✓	✓	-	✓	-	✓	-	-	-	-	-	✓
[46]	-	-	-	-	-	✓	-	✓	✓	-	-	-	-	✓	✓	✓	✓	-	✓	-	-	-	-	-	✓	-	-	-	-	✓
[47]	✓	✓	✓	-	✓	-	-	-	-	-	-	-	-	✓	✓	✓	✓	-	✓	-	-	-	-	✓	-	-	-	-	-	✓
[48]	✓	✓	✓	✓	-	✓	-	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-	✓	-	-	-	-	✓
[49]	✓	✓	✓	✓	✓	✓	-	✓	-	-	-	✓	-	✓	✓	✓	✓	-	✓	-	-	-	-	✓	✓	-	-	-	-	✓
[50]	-	-	-	-	-	-	-	-	✓	-	-	✓	-	✓	✓	-	✓	-	-	✓	-	✓	-	✓	-	-	-	-	-	-
[51]	✓	-	-	-	-	✓	✓	✓	-	-	-	✓	-	✓	✓	-	✓	-	✓	-	-	✓	-	-	-	-	-	-	-	✓
[52]	-	-	-	-	-	✓	✓	-	-	-	-	✓	-	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
[53]	✓	-	-	-	-	-	-	✓	-	-	-	✓	-	✓	✓	-	-	-	-	-	-	-	✓	✓	-	-	-	-	-	-
[54]	-	-	-	-	-	✓	✓	-	-	-	-	✓	-	✓	✓	-	✓	-	-	-	-	✓	✓	✓	-	-	-	-	-	-
[55]	-	-	-	-	-	✓	✓	-	-	-	-	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
[56]	-	-	-	-	-	✓	✓	✓	-	-	-	✓	-	✓	-	✓	✓	-	-	-	-	-	✓	✓	-	-	-	-	✓	-
[57]	-	-	-	-	-	✓	✓	-	-	-	-	-	-	✓	-	-	-	-	-	-	-	-	✓	✓	-	-	-	-	-	-
[58]	-	-	-	-	-	✓	✓	-	-	-	-	-	-	-	-	-	✓	-	-	-	-	-	-	✓	-	-	-	-	-	-

Abbreviations: No. corresponds to the reference number in the reference list, E (Elevation), S (Slope), A (Aspect), DTM (Digital Terrain Model), DEM (Digital Elevation Model), H (Hydrology), BP (Basin Management Plan), G (Geology), GM (Geomorphology), GC (General Command of Mapping), ME (Mineral Research and Exploration), So (Soil), SS (Soil Information System), F (Forest), V (Vegetation), EN (Endemics), FA (Fauna), FP (Forest Management Plan), C (Climate), LC (Land Cover), MP (Master Plan), CO (Coordination of Information on the Environment Database), RS (Remote Sensing), GIS (Geographic Information System), BB (Braun-Blanquet Method), NS (Network Sensors), LR (Light Detection and Ranging), KF (K-function Method), BI (Bioindicator), FO (Field Observations).

The methodological framework was developed by synthesizing key indicators from 15 international studies and evaluating 30 national biotope mapping studies across diverse ecological regions of Türkiye (Table 3). Selected studies fulfilled the following criteria: (i) conducted within Türkiye; (ii) included biotope, habitat, or ecological unit mapping; (iii) clearly defined data sources and analytical methods; and (iv) employed GIS, remote sensing, or field-based spatial assessment techniques.

The evaluation of Table 3 revealed that although the methods used in biotope mapping studies in Türkiye vary depending on the characteristics of the study areas, certain key data sources and indicators are commonly employed. In particular, vegetation, flora, land cover, Geographic Information Systems (GIS), topographic analyses, hydrological data, and forest management plans were identified as the most frequently used components for biotope identification.

In forest ecosystems, stand types, dominant woody species, and site characteristics are considered important indicators for defining biotopes, whereas in urban and rural studies, land-use patterns, land cover, hydrological structures, and landscape components are more prominent. In addition, physiographic variables such as elevation, slope, aspect, geology, and soil characteristics are widely used to explain the spatial distribution and ecological characteristics of biotopes.

A comparison of studies conducted in Türkiye with the international literature indicates that vegetation, land cover, topographic characteristics, hydrological features, and GIS-based spatial analyses constitute the core components of biotope mapping in both approaches (Tables 2 and 3). This similarity demonstrates that the methodological framework adopted in this study is consistent with both national and international biotope mapping approaches.

A substantial proportion of the reviewed studies applied GIS-based spatial analyses for biotope mapping, integrating remote sensing data, digital elevation models, and existing planning datasets. In contrast, advanced analytical techniques such as LiDAR, network sensors, K-function analysis, and similar approaches were used only in a limited number of studies. This finding indicates that biotope mapping studies in Türkiye are predominantly based on the integration of conventional ecological inventory approaches with GIS-based spatial analyses.

Based on the comprehensive review of 15 international and 30 national studies, the methodological framework adopted in this study was developed by integrating the most frequently used indicators identified in the literature with the spatial datasets available for the study area. Consequently, the proposed GIS-based biotope mapping framework is not limited to the Çınarcık District but represents a systematic and transferable approach that can be adapted to different ecological regions with similar environmental characteristics (Table 4).

Table 4. Frequency of indicators used in biotope mapping studies in Türkiye ($n = 30$) and their application in this study.

Indicator	Number of Studies	Frequency (%)	Used in This Study
V (Vegetation)	26	86.7	✓
GIS (Geographic Information System)	25	83.3	✓
F (Forest)	23	76.7	✓
FO (Field Observations)	22	73.3	-
So (Soil)	21	70	-
H (Hydrology)	20	66.7	✓
C (Climate)	19	63.3	-
E (Elevation)	18	60	✓
G (Geology)	16	53.3	-
FA (Fauna)	16	53.3	-
LC (Land Cover)	16	53.3	✓

Table 4. *Cont.*

Indicator	Number of Studies	Frequency (%)	Used in This Study
S (Slope)	15	50	-
A (Aspect)	14	46.7	-
RS (Remote Sensing)	13	43.3	-
FP (Forest Management Plan)	11	36.7	✓
GM (Geomorphology)	10	33.3	-
BB (Braun-Blanquet Method)	10	33.3	-
EN (Endemics)	9	30	-
CO (CORINE Database)	9	30	✓
DT (Digital Terrain Models)	8	26.7	-
MP (Basin Management Plan)	7	23.3	-
MP (Master Plan)	7	23.3	-
DM (Digital Elevation Map)	6	20	✓
ME (Mineral Research and Exploration)	6	20	-
BI (Bioindicator)	5	16.7	-
NS (Network Sensors)	2	6.7	-
GC (General Command of Mapping)	1	3.3	-
SS (Soil Information System)	0	0	-
LI (LIDAR)	0	0	-
KF (K-function Method)	0	0	-

The frequency analysis presented in Table 4 was used to identify the most commonly applied indicators in the literature and those compatible with the data structure of this study. Accordingly, vegetation (V), Geographic Information Systems (GIS), forest data (F), hydrology (H), elevation (E), land cover (LC), Forest Management Plan data (FP), CORINE land cover database, and Digital Elevation Model (DEM) were selected as the primary indicators for biotope identification. These indicators were integrated within a GIS environment to establish a biotope mapping framework incorporating land cover and land-use patterns, physiographic characteristics, hydrological structure, flora and vegetation composition, stand types, dominant woody species, and habitat characteristics.

Based on the literature review and comparative evaluation, the methodological approach adopted in this study is not limited to the case study area but is based on the synthesis of key indicators commonly used in national and international biotope mapping approaches. This approach provides a systematic and transferable framework that can be adapted to different ecological regions with similar environmental characteristics.

2.5. Spatial Analyses

All spatial analyses for biotope identification and mapping were performed in the ArcGIS Pro 3.2.2 environment using a GIS-based multi-layered analytical framework.

Initial spatial delineation of main land-cover classes (forest, agricultural, aquatic, and settlement areas) was established using the CORINE Land Cover (2018) database. To determine the physical site conditions, an elevation map was generated from the Digital Elevation Model (DEM). From this raster layer, key physiographic units—including plains, coastal plains, river valleys, plateaus, and mountainous areas—were classified based on ele-

vation ranges. This physiographic taxonomy served as a critical baseline for characterizing the topographic growing environment of the primary biotope types.

For forest ecosystem mapping, the Çınarcık Forest Management Plan (2017) served as the primary field-based ecological dataset [11]. This database is derived from a systematic forest inventory conducted by the General Directorate of Forestry, utilizing 561 sampling plots established at regular 300×300 m grid intervals [11]. Stand characteristics, dominant tree species, stand structures (pure vs. mixed), forest functions, degraded forest zones, and site conditions extracted from these plot measurements were processed in the GIS environment to define and map distinct forest biotopes.

To supplement the forest inventory and refine sub-biotope classifications, floristic data were integrated from the Turkish Plants Data Service (TÜBİVES) and the historical flora study of the Armutlu Peninsula by İnan [13,14]. The latter study recorded 69 herbaceous plant taxa using the Braun-Blanquet method across sampling plots measuring 400 m^2 for woody layers and 100 m^2 for herbaceous layers [14]. Spatial and habitat attributes from these floristic records were updated to reflect current taxonomic classifications, compiled into a unified database, and evaluated to assess species diversity, endemic taxa, and local habitat affinities.

Finally, geological, hydrological, and built-environment layers were synthesized with the land-cover and forest datasets. Spatial relationships and ecological interactions between natural and anthropogenic components were analyzed using Overlay Analysis, Buffering, Reclassification, and Spatial Analyst tools in ArcGIS Pro.

The outputs generated from each thematic layer were subsequently integrated through overlay operations, allowing the simultaneous evaluation of physiographic conditions, vegetation characteristics, forest stand attributes, hydrological features, and land-use patterns during the biotope delineation process.

No additional field-based vegetation survey was carried out during the present study. Instead, forest inventory data, floristic databases, and officially published spatial datasets were integrated within the GIS environment to identify and classify biotopes.

Classification Rules and Overlay Sequence

To improve methodological transparency, the general sequence and logic of the overlay-based classification process are summarized below.

Main biotope boundaries (forest, agricultural, aquatic, and urban) were first delineated using the relevant land-cover classes of the CORINE Land Cover (2018) dataset as the base layer. Within the resulting forest extent, Forest Management Plan (FMP) stand and compartment data were overlaid to refine forest boundaries and to determine sub-biotope types, based on the dominant woody species and stand composition recorded for each compartment: stands with a single recorded dominant species were classified accordingly (e.g., “*Fagus orientalis* Forest”), while stands with two co-dominant species were classified as mixed sub-biotopes (e.g., “*Fagus orientalis*–*Castanea sativa* Forest”). For aquatic, agricultural, and urban biotopes, sub-classification was based directly on the relevant attributes of the source datasets (hydrological network type, agricultural land-use category, and settlement/green-space type, respectively), rather than a multi-criteria overlay, given the absence of species-level field data for these biotope types (see Section 2.6).

All resulting layers were processed in ArcGIS Pro 3.2.2 using standard reclassification, buffering, and overlay analysis operations, consistent with the general GIS workflow described in Section 2.3. The resulting polygons were subjected to topological controls to verify spatial integrity, as described in Section 2.7. No formal minimum mapping unit (MMU) threshold or automated conflict-resolution rule between overlapping layers was

applied; boundary refinements were performed manually within the GIS environment based on the finer-resolution FMP compartment data in forest areas.

2.6. Biotope Classification

Within the scope of this study, biotopes were classified into four main biotope groups, namely forest, aquatic, agricultural, and urban biotopes, based on land cover, land use characteristics, and ecological structure.

In this study, the term “biotope” is used in the broader landscape-ecological sense established in the European biotope mapping tradition [3,4,15], in which land cover, physiographic structure, and vegetation/stand composition serve as spatial surrogates for habitat units rather than requiring exhaustive faunal inventories for every biotope type. This approach is consistent with the majority of the national and international studies reviewed in this paper (Tables 2 and 3), where vegetation, land cover, and physiographic indicators—rather than direct faunal survey data—constitute the primary basis for biotope delineation. Direct floristic evidence was available for forest biotopes through the integration of Forest Management Plan inventory data and historical flora records; however, for aquatic, agricultural, and urban biotopes, boundaries were delineated primarily on the basis of land cover, hydrological structure, and land-use patterns rather than species-level floristic or faunal inventories, as such data were not available within the scope of this study. This distinction should be considered when interpreting the biological specificity of the different biotope types identified.

The identification of the main biotope groups was based on the integrated assessment of land cover, stand structure, flora composition, vegetation characteristics, hydrological structure, and growing environment conditions. Each main biotope was further divided into sub-biotope types according to ecological similarities by considering dominant plant species, woody species composition, habitat characteristics, stand types, and land use properties.

For forest biotopes, stand types, dominant woody species, and vegetation structure were used as primary classification criteria; for aquatic biotopes, hydrological characteristics and water-related habitats were considered; for agricultural biotopes, land use patterns and agricultural production systems were evaluated; and for urban biotopes, settlement patterns and urban green spaces were used as classification criteria.

The resulting hierarchical classification enabled the representation of habitat heterogeneity at both the main biotope and sub-biotope levels while maintaining consistency with the ecological indicators identified from the literature review.

2.7. Generation of the Biotope Map

The biotope map was generated by integrating the GIS database, spatial analyses, and biotope classification criteria established in the previous stages. Data layers related to land cover, topography, hydrology, geology, flora, vegetation, stand structure, and land use were evaluated together within the GIS environment to determine biotope boundaries.

Initially, the main biotope boundaries representing forest, agricultural, aquatic, and urban areas were delineated using CORINE Land Cover data. Subsequently, forest biotopes were divided into sub-biotope types based on stand types, dominant woody species, forest functions, and vegetation characteristics derived from the Forest Management Plan data. Similarly, sub-classifications of aquatic, agricultural, and urban biotopes were defined by considering hydrological characteristics, coastal areas, agricultural land-use patterns, and settlement structures.

All biotope boundaries were processed within the GIS environment, and biotope polygons were generated through overlay analysis, reclassification, buffer analysis, and

spatial query operations. The resulting polygons were subjected to topological controls, their spatial integrity was verified, and the area and proportional distribution of each biotope type were calculated.

The completed biotope map constitutes the final spatial product of the proposed GIS-based biotope mapping framework and provides the basis for all subsequent ecological evaluations presented in the Section 3.

It should be noted that the resulting biotope map represents a preliminary, inventory-based classification derived from the integration of existing institutional datasets, rather than a field-validated product; formal accuracy assessment was beyond the scope of this study and is identified as a priority for future research (Section 4.3). The methodological workflow adopted for biotope identification and mapping is illustrated in Figure 3.

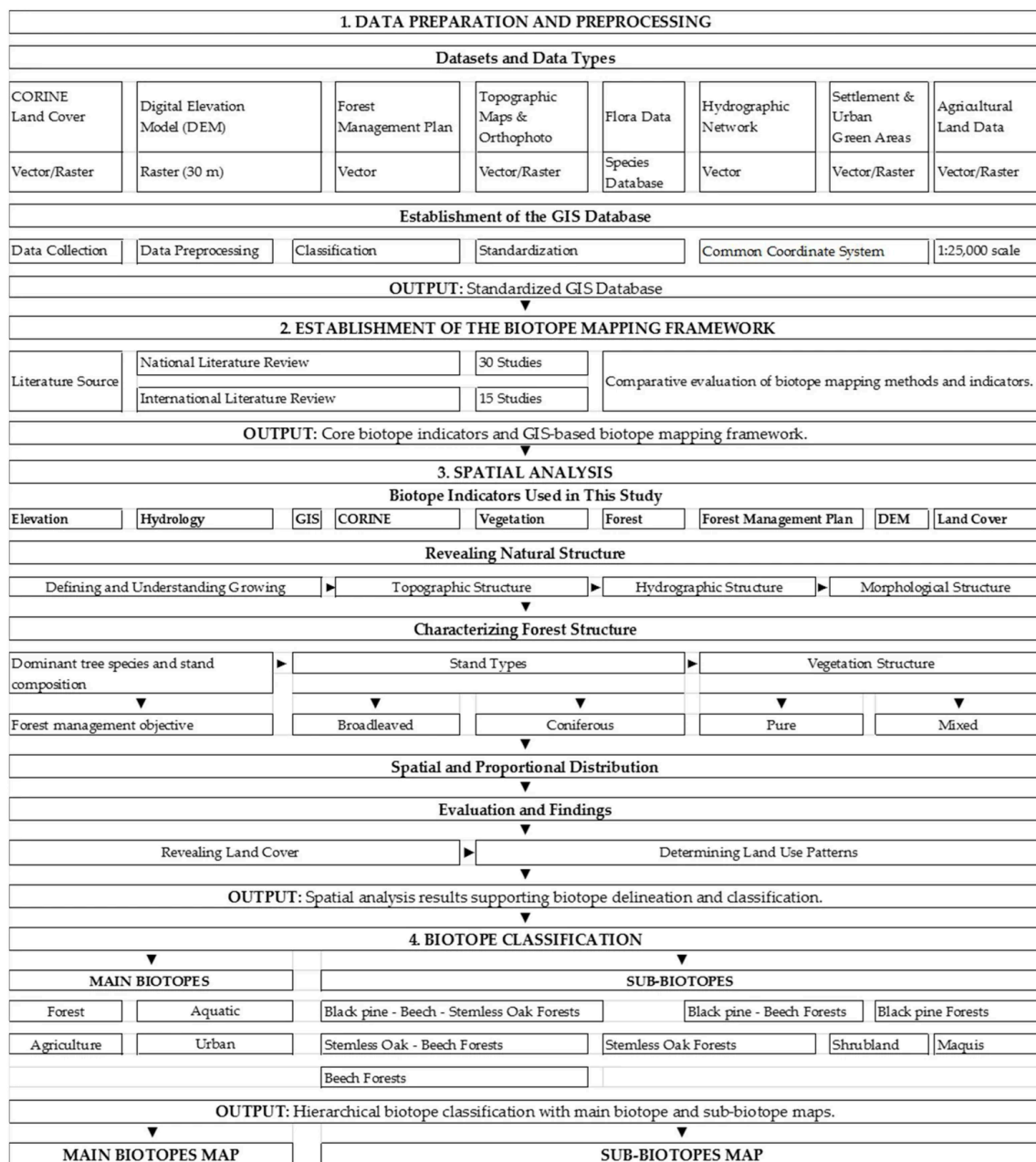


Figure 3. Methodological workflow for GIS-based biotope identification and mapping.

3. Results

3.1. Forest Resources and Floristic Elements of Çınarcık District

According to the land cover data, Çınarcık District has a heterogeneous landscape structure comprising forest, agricultural, coastal, aquatic, and settlement areas. Based on the CORINE (2018) land cover data, approximately 60% of the study area consists of forest and agricultural areas [9].

In terms of floristic characteristics, the study area is located within the transition zone between the Mediterranean and Euro-Siberian phytogeographical regions and exhibits high plant diversity. According to the floristic study conducted by İnan [14] on the Armutlu Peninsula, numerous woody and herbaceous taxa belonging to both Mediterranean and Euro-Siberian flora regions occur within the study area. The main floristic elements identified in the study area are presented in Table 5.

Table 5. Main floristic elements identified in Çınarcık District. (a,b) Location and growing environment of herbaceous plant taxa, compiled from İnan [14] and adapted to current classification.

No	Mediterranean Flora Elements	No	Euro-Siberian Flora Elements
1	<i>Arbutus andrachne</i> L.	1	<i>Acer campestre</i> L.
2	<i>Asphodeline lutea</i> (L.) Rchb.	2	<i>Acer platanoides</i> L.
3	<i>Cistus creticus</i> L.	3	<i>Carpinus betulus</i> L.
4	<i>Cistus salvifolius</i> L.	4	<i>Castanea sativa</i> Mill.
5	<i>Holcus lanatus</i> L.	5	<i>Cornus mas</i> L.
6	<i>Inula graveolens</i> (L.) Desf.	6	<i>Eupatorium cannabinum</i> L.
7	<i>Juniperus oxycedrus</i> L. subsp. <i>oxycedrus</i>	7	<i>Fagus orientalis</i> Lipsky
8	<i>Muscari neglectum</i> Guss.	8	<i>Fraxinus ornus</i> L.
9	<i>Olea europaea</i> L.	9	<i>Silene italica</i> L.
10	<i>Phillyrea latifolia</i> L.	10	<i>Quercus cerris</i> L.
11	<i>Pinus brutia</i> Ten.	11	<i>Quercus frainetto</i> Ten.
12	<i>Pinus pinea</i> L.	12	<i>Quercus robur</i> L.
13	<i>Pistacia terebinthus</i> L.	13	<i>Sorbus torminalis</i> (L.) Crantz subsp. <i>torminalis</i>
14	<i>Quercus coccifera</i> L.	14	<i>Taxus baccata</i> L.
15	<i>Quercus infectoria</i> Oliv.	15	<i>Tilia tomentosa</i> Moench
16	<i>Rhus coriaria</i> L.	16	<i>Tussilago farfara</i> L.
17	<i>Rubus discolor</i> Weihe & Nees	17	<i>Trifolium arvense</i> L.
18	<i>Spartium junceum</i> L.	18	<i>Hypericum bithynicum</i> Boiss.
No	Latin Name	Location and Growing Environment	
1	<i>Arum italicum</i> Mill.	a	
2	<i>Asparagus acutifolius</i> L.	Near Çınarcık, Teşvikiye Village	
3	<i>Ballota nigra</i> L.	Between Çınarcık- Üçreisler	
4	<i>Sedum sediforme</i> (Jacq.) Pau	Between Çınarcık- Üçreisler	
5	<i>Calicotome villosa</i> (Poir.) Link	2 km from Esenköy	
6	<i>Clematis vitalba</i> L.	A small number in forested areas above Çınarcık	
7	<i>Carlina vulgaris</i> L.	In scrub and wooded areas	
8	<i>Chrysanthemum segetum</i> L.	Between Çınarcık and Şenköy	
9	<i>Conyza bonariensis</i> L. Cronquist	Çınarcık 2 km. west, mountain slopes and forest clearings	
10	<i>Dorycnium pentaphyllum</i> Scop.	Between Çınarcık- Üçreisler	
11	<i>Erysimum cuspidatum</i> (M. Bieb.) DC.	Between Çınarcık- Üçreisler	
12	<i>Erica arborea</i> L.	Between Çınarcık and Şenköy, in semi-shaded areas	
13	<i>Euonymus latifolius</i> (L.) Mill.	Between Armutlu and Çınarcık, in the pseudomaquis vegetation	
14	<i>Epilobium hirsutum</i> L.	Upper areas of Çınarcık-Şenköy, with a few individuals within the forest	
15	<i>Euphorbia stricta</i> L.	Between Çınarcık- Üçreisler	
		Along the roadside between Armutlu and Çınarcık	

Table 5. Cont.

No	Mediterranean Flora Elements	No	Euro-Siberian Flora Elements
16	<i>Euphorbia myrsinites</i> L.		Between Çınarcık Road and Teşvikiye Village
17	<i>Galium verum</i> L.		Between Çınarcık and Şenköy, in forest clearings
18	<i>Geum urbanum</i> L.		Upper areas of Çınarcık
19	<i>Knautia integrifolia</i> (L.) Bertol.		Upper areas of Çınarcık
20	<i>Hedera helix</i> L.		Climbing species on forest trees between Armutlu and Çınarcık
21	<i>Holcus lanatus</i> L.		Between Çınarcık and Üçreisler, and in the upper areas of Çınarcık/Şenköy
22	<i>Hypericum perforatum</i> L.		Around the Çınarcık–Üçreisler area
23	<i>Lactuca saligna</i> L.		Çınarcık- Şenköy
24	<i>Lotus corniculatus</i> L.		Around the Çınarcık–Üçreisler area
25	<i>Lonicera etrusca</i> Santi		Around the Çınarcık–Üçreisler area
26	<i>Lycopus europaeus</i> L.		Around the Çınarcık–Üçreisler area
27	<i>Lysimachia atropurpurea</i> L.		Upper areas of Çınarcık–Şenköy, along stream banks
28	<i>Lythrum salicaria</i> L.		2 km from Esenköy
29	<i>Lythrum hyssopifolia</i> L.		Between Çınarcık- Üçreisler
30	<i>Malva sylvestris</i> L.		Between Çınarcık- Üçreisler
31	<i>Mentha aquatica</i> L.		Between Çınarcık- Üçreisler
32	<i>Mercurialis perennis</i> L.		Upper areas of Çınarcık–Şenköy, moist sites within the forest
33	<i>Mespilus germanica</i> L.		Upper areas of Çınarcık
34	<i>Nigella elata</i> Boiss.		Çınarcık–Armutlu road
35	<i>Pallenis spinosa</i> (L.) Cass.		Upper areas of Çınarcık
36	<i>Paliurus spina-christi</i> Mill.		Upper areas of Çınarcık, shrublands and woodlands within the pseudomaquis
		b	
37	<i>Psoralea bituminosa</i> L.		Between Çınarcık and Üçreisler, in forest clearings and shaded areas
38	<i>Pastinaca sativa</i> L.		Between Çınarcık- Üçreisler
39	<i>Potentilla recta</i> L.		Upper areas of Çınarcık–Şenköy
40	<i>Orobanche minor</i> Sm.		Upper areas of Çınarcık
41	<i>Orchis laxiflora</i> Lam.		2 km west of Çınarcık, mountain slopes
42	<i>Ononis mitissima</i> L.		Between Çınarcık- Üçreisler
43	<i>Prunella vulgaris</i> L.		Between Çınarcık- Üçreisler
44	<i>Parietaria judaica</i> L.		Between Çınarcık- Üçreisler
45	<i>Prunella laciniata</i> (L.) L.		Between Çınarcık- Üçreisler
46	<i>Ranunculus constantinopolitanus</i> d’Urv.		Between Çınarcık/Karpuzdere, few individuals in open areas
47	<i>Rosa sempervirens</i> L.		2 km beyond Esenköy, seaside
48	<i>Rubus discolor</i>		Throughout the Çınarcık district
49	<i>Ruscus aculeatus</i> L.		Upper areas of Çınarcık–Şenköy, among pseudomaquis shrublands
50	<i>Rhus coriaria</i>		Çınarcık–Karpuzdere, within pseudomaquis, in shrubs and forests
51	<i>Saponaria officinalis</i> L.		Upper areas of Çınarcık
52	<i>Salvia forskahlei</i> L.		Upper areas of Çınarcık–Şenköy, among shrubs and clearings
53	<i>Salvia napifolia</i> Jacq.		Between Çınarcık- Üçreisler
54	<i>Salvia virgata</i> Jacq.		Between Çınarcık- Üçreisler
55	<i>Salvia verbenaca</i> L.		Between Çınarcık- Üçreisler
56	<i>Securigera securidaca</i> (L.) Degen & Dörf.		Between Çınarcık- Üçreisler
57	<i>Sanguisorba minor</i> Scop.		Between Çınarcık- Üçreisler
58	<i>Solanum alatum</i> Moench		Between Çınarcık- Üçreisler
59	<i>Sorbus aucuparia</i> L.		Upper areas of Çınarcık, in <i>Fagus</i> spp. and mixed forests

Table 5. Cont.

No	Mediterranean Flora Elements	No	Euro-Siberian Flora Elements
60	<i>Spartium junceum</i> L.		Between Çınarcık and Üçreisler
61	<i>Sorbus torminalis</i>		Upper areas of Çınarcık, together with <i>Fagus</i> spp. and <i>Carpinus</i> spp.
62	<i>Tussilago farfara</i>		Between Çınarcık–Üçreisler
63	<i>Teucrium chamaedrys</i> L.		Between Çınarcık–Üçreisler
64	<i>Silene italica</i>		Between Çınarcık and Şenköy
65	<i>Silene alba</i> (Mill.) E. H. L. Krause		West of Çınarcık, on mountain slopes and forest clearings
66	<i>Trifolium stellatum</i> L.		Around Çınarcık–Şenköy, in meadows and open areas
67	<i>Ulmus minor</i> Mill. subsp. minor		Between Çınarcık and Şenköy
68	<i>Urtica dioica</i> L.		Between Çınarcık–Üçreisler
69	<i>Vaccinium myrtillus</i> L.		Upper areas of Çınarcık–Şenköy

Detailed information on herbaceous plant taxa, including their locations and growing environments, was compiled from İnan [14] and adapted to current taxonomic classifications. The identified herbaceous taxa and their habitat characteristics are presented in Table 5a,b.

According to the Çınarcık Forest Management Plan, the study area contains 39 woody tree species and maquis communities. These woody species were evaluated as important indicators for the identification and classification of forest biotopes [11]. The main woody species occurring within the forest ecosystems are presented in Table 6.

Table 6. Woody tree species of Çınarcık District forest stands.

No	Latin Name	No	Latin Name	No	Latin Name
1	<i>Acer</i> spp.	13	<i>Fraxinus angustifolia</i> Vahl	25	<i>Pyrus elaeagnifolia</i> Pall.
2	<i>Alnus glutinosa</i> (L.) Gaertn.	14	<i>Fraxinus excelsior</i> L.	26	<i>Cotinus coggygria</i> Scop.
3	<i>Arbutus unedo</i> L.	15	<i>Laurocerasus officinalis</i> M. Roem.	27	<i>Robinia pseudoacacia</i> L.
4	<i>Carpinus betulus</i>	16	<i>Laurus nobilis</i> L.	28	<i>Salix</i> spp.
5	<i>Carpinus orientalis</i> Mill.	17	<i>Paliurus spina-christi</i>	29	<i>Tilia tomentosa</i>
6	<i>Castanea sativa</i> Mill.	18	<i>Phillyrea latifolia</i>	30	<i>Cotinus coggygria</i>
7	<i>Cerasus avium</i> (L.) Moench	19	<i>Pinus nigra</i> J. F. Gmel.	31	<i>Tamarix tetrandia</i> Pall. ex M.Bieb.
8	<i>Corylus avellana</i> L.	20	<i>Pinus pinea</i>	32	<i>Mespilus germanica</i>
9	<i>Cornus mas</i>	21	<i>Pistacia terebinthus</i>	33	<i>Quercus petraea</i> (Matt.) Liebl.
10	<i>Crataegus monogyna</i> Jacq.	22	<i>Platanus orientalis</i> L.	34	<i>Quercus frainetto</i>
11	<i>Crataegus orientalis</i> Pall. ex M. Bieb.	23	<i>Populus tremula</i> L.	35	<i>Quercus cerris</i>
12	<i>Fagus orientalis</i>	24	<i>Prunus domestica</i>		Maquis Community

Although administrative and legally classified as forest land, maquis areas are not composed of typical forest stand species; rather, they are dominated by sessile oak (*Quercus petraea*), with laurel (*Laurus nobilis*) occurring as a scattered component alongside numerous accompanying shrub taxa [11].

According to the Çınarcık Forest Management Plan, 72 different stand types occur within the study area [11]. Oriental beech (*Fagus orientalis*), silver lime (*Tilia tomentosa*), sweet chestnut (*Castanea sativa*), and sessile oak (*Quercus petraea*) constitute the dominant tree species within these stands. Particularly, *Fagus orientalis*, *Tilia tomentosa*–*Castanea sativa*, *Quercus petraea*–*Fagus orientalis*, and *Tilia tomentosa*–*Fagus orientalis* mixed stands represent the most widely distributed forest communities in the study area.

The forest ecosystems were also evaluated according to their management objectives defined in the Forest Management Plan [11]. These objectives include timber production,

biodiversity conservation, hydrological protection, erosion control, recreation, and eco-tourism functions. The relationship between dominant tree species, stand composition, and forest management objectives is presented in Table 7.

Table 7. Forest management objectives and rotation periods according to dominant tree species and stand composition in Çınarcık District.

Dominant Species/Stand	Management Objective	Rotation Period (Years)
<i>Pinus nigra</i>	Timber production; high forest management	120
<i>Pinus pinea</i>	Timber production	100
<i>Pinus pinaster</i> Aiton	Timber production	30
<i>Fagus orientalis</i> - <i>Tilia tomentosa</i>	Timber production	120
<i>Quercus petraea</i> - <i>Fagus orientalis</i>	Firewood supply; conversion to high forest	100
<i>Quercus petraea</i> - <i>Fagus orientalis</i>	Non-wood forest products, erosion control and biodiversity	120
<i>Tilia tomentosa</i> - <i>Castanea sativa</i>	Non-wood forest products	120
<i>Quercus petraea</i>	Nature conservation	200
<i>Platanusorientalis</i>	Gene conservation	200
<i>Fagus orientalis</i>	Delmece Plateau Nature Park management	200
<i>Tilia tomentosa</i>	Erosion prevention and soil conservation	200
<i>Tilia tomentosa</i> -Maquis	Soil conservation	200
<i>Castanea sativa</i> - <i>Fagus orientalis</i>	Hydrological protection	200
<i>Fagus orientalis</i>	Public health function; Yalova Urban Forest	200
<i>Pinus pinaster</i> -Maquis	Aesthetic conservation	200
<i>Tilia tomentosa</i> - <i>Quercus petraea</i>	Ecotourism/recreation	200
Maquis Communities	Nature conservation	200

Rotation periods varied between 30 and 120 years for stands managed primarily for timber production, whereas all ecologically and socioculturally oriented management classes were assigned a uniform rotation period of 200 years, reflecting a substantially longer-term management approach for conservation-oriented forest areas.

The *Platanus orientalis* gene conservation forest (national registry no. 316) is designated within compartments 38 and 41 of the planning unit, aiming to conserve the genetic diversity of the species in situ. Delmece Plateau, declared a Nature Park by the Ministry's decision dated 11 July 2011 (No. 903), is managed according to nature park conservation criteria [11].

Beyond the species-based management classification presented above, the areal distribution of forest functions was further examined to quantify their spatial extent within the district. Forest production and public health functions were found to cover the largest areas, accounting for 53.53% and 34.82% of the total forest area, respectively, and together representing approximately 88% of all forest functions in the district (Table 8).

Table 8. Forest functions and their areal and proportional distribution.

Function	Area (ha)	Ratio (%)	Function	Area (ha)	Ratio (%)
Public Health	7.234	34.82	Forest Production	11.119	53.53
Soil Protection	1.128	5.43	Aesthetic	564	2.71
Water Protection	97	0.47	Nature Conservation	564	2.71
Recreation and Tourism Area	47	0.23	Non-Forest Area/Land	20	0.09
			Total	20,773	100

Beyond their ecological and management functions, forest resources also play an important socioeconomic role for local communities. Approximately 60% of the district population is employed in the tourism sector, while the remaining 40% is engaged in forestry-related labor, olive cultivation, greenhouse farming, floriculture, fishing, beekeeping, and small-scale livestock farming. Local communities benefit from forest resources primarily through timber harvesting and afforestation-related activities (planting, hoeing), as well as young stand tending operations. In addition, forests provide subsistence fuelwood and construction timber, local market products such as linden flowers and chestnuts, recreational areas, and spaces for nature-based sports [11].

Collectively, these findings indicate that the forest resources of Çınarcık District are structurally diverse and multifunctional, combining high floristic richness with a management framework that integrates timber production, ecological protection, and community-based socioeconomic uses—characteristics that directly shape the composition and distribution of the biotope types identified in the Section 3.2.

3.2. Main and Sub-Biotopes of Çınarcık District

3.2.1. Main Biotopes and Dominant Characteristics

The identification of the main biotopes in Çınarcık District was based on the integrated evaluation of land cover, topographic and morphological characteristics, hydrological structure, site conditions, and forest stand types. In the classification of forest biotopes, stand types, dominant woody species, and the characteristics of coniferous, broadleaved, and mixed forests were used as the main criteria. As a result of the assessment, four main biotope groups were identified within the study area: forest, aquatic, agricultural, and urban biotopes (Table 9, Figure 4).

Table 9. Main biotope types, growing environments and dominant stand characteristics.

No	Main Biotope	Topographical and Morphological	Hydrological	Dominant Land Cover/Vegetation Type
1	Forest	High mountainous area	Near a stream	Coniferous, broadleaved and mixed forests
		Sloping area	Near a lake	
2	Aquatic	Valley	Stream, lake and pond	Coniferous, broadleaved and mixed forests
3	Agriculture	Mountainous area, coastal plain, low plateau	Areas close to water sources	Agricultural areas
4	Urban	Coastal plain	Stream, lake and pond	Scrub communities and heathlands

Forest biotopes constitute the largest biotope group within the study area. Çınarcık District is located within the transition zone between the Mediterranean and Euro-Siberian phytogeographical regions and hosts approximately 620 plant taxa, including endemic species. Within the forest biotopes, broadleaved, coniferous, and mixed stand types were distinguished.

In broadleaved forest biotopes, the dominant species are Oriental beech (*Fagus orientalis*), narrow-leaved ash (*Fraxinus angustifolia*), Oriental plane (*Platanus orientalis*), silver lime (*Tilia tomentosa*), sweet chestnut (*Castanea sativa*), and sessile oak (*Quercus petraea*). These biotopes are mainly distributed across mountainous areas, lower stream valleys, and relatively flat topographic units.

Coniferous forest biotopes consist of black pine (*Pinus nigra*), Turkish red pine (*Pinus brutia*), maritime pine (*Pinus pinaster*), and stone pine (*Pinus pinea*). These biotopes cover

a limited proportion of the study area and are mainly concentrated on high plateaus and steep slopes. Among coniferous forest biotopes, *Pinus pinaster* has the widest spatial distribution [11,14].

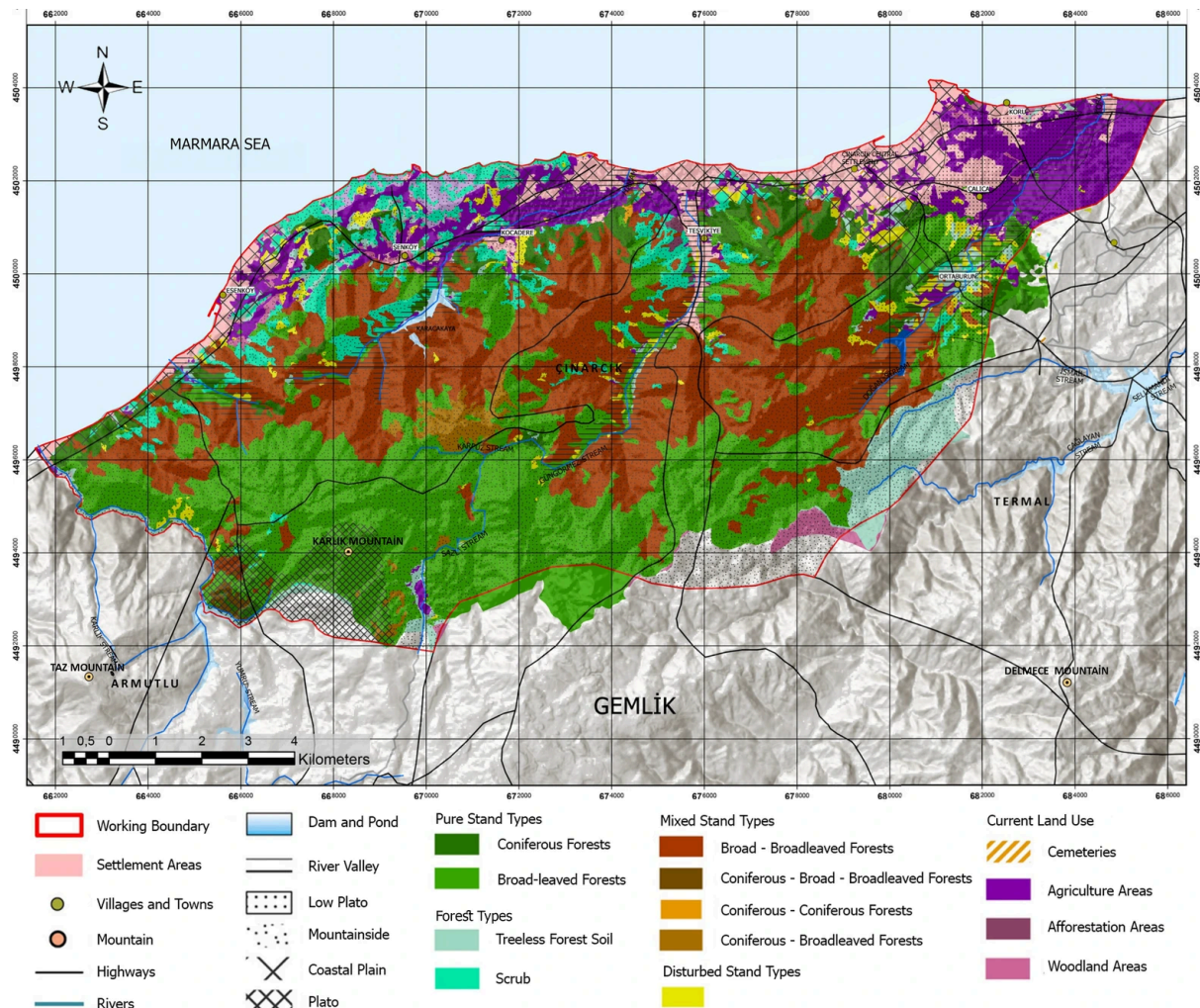


Figure 4. Distribution of the main biotope types in Çınarcık District (WGS 1984 UTM Zone 35N).

When forest biotopes were evaluated according to pure and mixed stand structures, four dominant woody species were identified in pure coniferous stands and six dominant woody species in pure broadleaved stands. Among pure coniferous stands, *Pinus pinaster* had the largest spatial distribution, whereas *Fagus orientalis* was the dominant species among pure broadleaved stands (Table 10). Among pure stands, *Fagus orientalis* represented the most dominant species, accounting for 61.05% of the total pure stand area, followed by *Quercus petraea* (14.82%) and *Pinus pinaster* (10.37%). These three species together accounted for approximately 86% of the total pure stand area.

Mixed forest biotopes consist of *Quercus petraea*–*Fagus orientalis*, *Quercus petraea*–*Tilia tomentosa*, *Tilia tomentosa*–*Fagus orientalis*, *Fagus orientalis*–*Fraxinus angustifolia*, and *Pinus pinaster*–*Pinus pinea* associations. These biotopes represent the forest ecosystems with the highest biodiversity within the study area due to the co-occurrence of different species within the same habitat.

Among mixed stand types, the association with the largest spatial distribution is *Fagus orientalis*–*Castanea sativa* (33.86%), followed by *Tilia tomentosa*–*Castanea sativa* (19.38%) and *Quercus petraea*–*Castanea sativa* (18.24%). These three associations together account for approximately 71.48% of the total mixed stand area (Table 11).

Table 10. Distribution of forest main biotopes according to pure stand types.

Stand Type	No	Name	Latin Name	Area (ha)	Ratio (%)
Coniferous	1	Red pine	<i>Pinus brutia</i>	3	0.04
	2	Stone pine	<i>Pinus pinea</i>	83	1.24
	3	Coastal pine	<i>Pinus pinaster</i>	693	10.37
	4	Black pine	<i>Pinus nigra</i>	53	0.79
Broadleaved	1	Oriental beech	<i>Fagus orientalis</i>	4082	61.05
	2	Stemless oak	<i>Quercus petraea</i>	991	14.82
	3	Ash	<i>Fraxinus excelsior</i>	13	0.19
	4	Silver lime	<i>Tilia tomentosa</i>	191	2.86
	5	Oriental plane	<i>Platanus orientalis</i>	110	1.65
	6	Sweet chestnut	<i>Castanea sativa</i>	467	6.99
				Total 6686	100

Table 11. Distribution of forest main biotopes according to mixed stand types.

No	Latin Name	Area (ha)	Ratio (%)
1	<i>Fagus orientalis-Quercus petraea-Pinus nigra</i>	50	0.91
2	<i>Fagus orientalis-Quercus petraea</i>	293	5.36
3	<i>Tilia tomentosa-Castanea sativa</i>	1059	19.38
4	<i>Quercus petraea-Castanea sativa</i>	997	18.24
5	<i>Quercus petraea-Tilia tomentosa</i>	224	4.10
6	<i>Tilia tomentosa-Fagus orientalis</i>	742	13.58
7	<i>Fagus orientalis-Castanea sativa</i>	1851	33.86
8	<i>Pinus nigra-Fagus orientalis</i>	241	4.41
9	<i>Pinus pinaster-Pinus pinea</i>	9	0.16
		Total 5466	100

Aquatic biotopes consist of various habitats, including lakes, ponds, streams, river systems, wetlands, and coastal aquatic areas. The distribution of hydrophytic plant communities inhabiting these environments is strongly influenced by environmental factors such as water salinity, temperature, light availability, water depth, and hydrological conditions. Therefore, aquatic biotopes are considered fundamental ecological components of landscapes in terms of habitat heterogeneity and biodiversity conservation [59].

In this study, aquatic biotopes were not identified based on species-level aquatic flora inventories; instead, they were delineated through the integrated evaluation of land cover, hydrological structure, site conditions, and Forest Management Plan data [11]. Accordingly, aquatic environments were delineated only at the main biotope level and were not further subdivided into sub-biotope types, as species-level aquatic vegetation inventories were beyond the scope of this study. Within this framework, stream channels, river corridors, ponds, reservoir areas, and moist habitats surrounding these water bodies were classified as aquatic biotopes. The delineation of aquatic biotope boundaries was based on the combined assessment of hydrological structures and the natural and semi-natural vegetation surrounding these areas.

Within the study area, aquatic biotopes consist of streams, valley bottoms, reservoir areas, and moist habitats associated with water resources. These areas form ecological transition zones together with adjacent coniferous, broadleaved, and mixed forest biotopes, providing important habitats for maintaining ecological continuity and biodiversity [31].

Agricultural biotopes comprise rainfed agricultural lands, irrigated agricultural areas, fallow fields, and olive groves located in mountainous areas, river valleys, coastal plains, and plateau surfaces. These areas are not only production landscapes but also agroecosystems interacting with natural and semi-natural habitats. Agricultural biotopes provide important ecological functions in maintaining landscape heterogeneity, sustaining habitat connectivity, and supporting biodiversity [27].

Urban biotopes consist of settlement areas and associated parks, urban green spaces, cemeteries, stream corridors, coastal areas, wetlands, forest patches, shrublands, and maquis communities located within or around urban environments. Urban biotopes contribute to the maintenance of ecological connectivity by supporting the continuity of natural and semi-natural habitats within built environments. Particularly, urban green spaces represent important ecological components for sustaining habitat diversity and supporting urban biodiversity [23]. In the study area, old cemeteries, forest patches, military areas, flood-prone areas, stream corridors, historical structure surroundings, parks, and other open green spaces were evaluated as relatively well-preserved urban biotopes. In this study, species-based floristic inventories were not conducted for agricultural and urban biotopes; instead, the boundaries of these biotopes were determined based on land use, growing environment characteristics, and available spatial datasets.

Overall, these results demonstrate that forest biotopes dominate the landscape mosaic of Çınarcık District, reflecting the strong influence of topography and forest management practices on habitat distribution, while aquatic, agricultural, and urban biotopes occupy comparatively smaller but ecologically complementary portions of the study area, contributing to overall landscape connectivity and habitat heterogeneity.

3.2.2. Sub-Biotope Types and Dominant Species

By distinguishing the main biotope groups according to ecological similarity and growing environment characteristics, 12 characteristic sub-biotope types were identified within the study area (Table 12). Among the identified sub-biotope types, Beech Forests (*Fagus orientalis*) occurring in plateau environments had the largest spatial distribution, accounting for 36.40% of the total sub-biotope area. This was followed by maquis communities in plateau environments (18.58%) and maquis communities in coastal plain environments (17.90%). Together, these three sub-biotope types represented approximately 73% of the total mapped sub-biotope area.

Eight disturbed biotope types resulting from anthropogenic activities and natural processes were identified within the study area. Among these disturbed biotopes, maquis communities (53.13%) and Sessile oak forests (37.02%) represented the largest proportions, together accounting for approximately 90% of the total disturbed biotope area (Table 13, Figure 5).

Table 12. Sub-biotope types, growing environments and their spatial distribution.

No	Sub-Biotope Type	Growing Environment	Area (ha)	Ratio (%)
1	Black pine–Beech–Sessile Oak Forests	Plateau	60	5.12
2	Black pine-Beech Forests	Plateau	12	1.02
3	Black pine Forests	Plateau	1	0.09
4	Sessile Oak-Beech Forests	Plateau	30	2.56
5	Sessile Oak Forests	Plateau	64	5.46
6	Beech Forests	Plateau	445	37.93
7	Shrubland Communities	Stream Valley	38	3.24
8	Shrubland Communities	Coastal Plain	210	17.90
9	Maquis Communities	Olive Groves	16	1.36

Table 12. Cont.

No	Sub-Biotope Type	Growing Environment	Area (ha)	Ratio (%)
10	Maquis Communities	Coastal Plain	5	0.43
11	Maquis Communities	Plateau	218	18.58
12	Maquis Communities	Coastal Plain-Agricultural Land	74	6.31
			Total 1173	100

Table 13. Disturbed biotope types and their spatial distribution.

Disturbed Biotope Type	Area (ha)	Ratio (%)
1 Maquis Communities	221	53.13
2 Hornbeam Forests	2	0.48
3 Sycamore tree forests	17	4.09
4 Linden Forests	3	0.72
5 Beech Forests	8	1.92
6 Chestnut Forests	9	2.16
7 Stemless oak Forests	154	37.02
8 Black pine Forests	2	0.48
Total 416		100

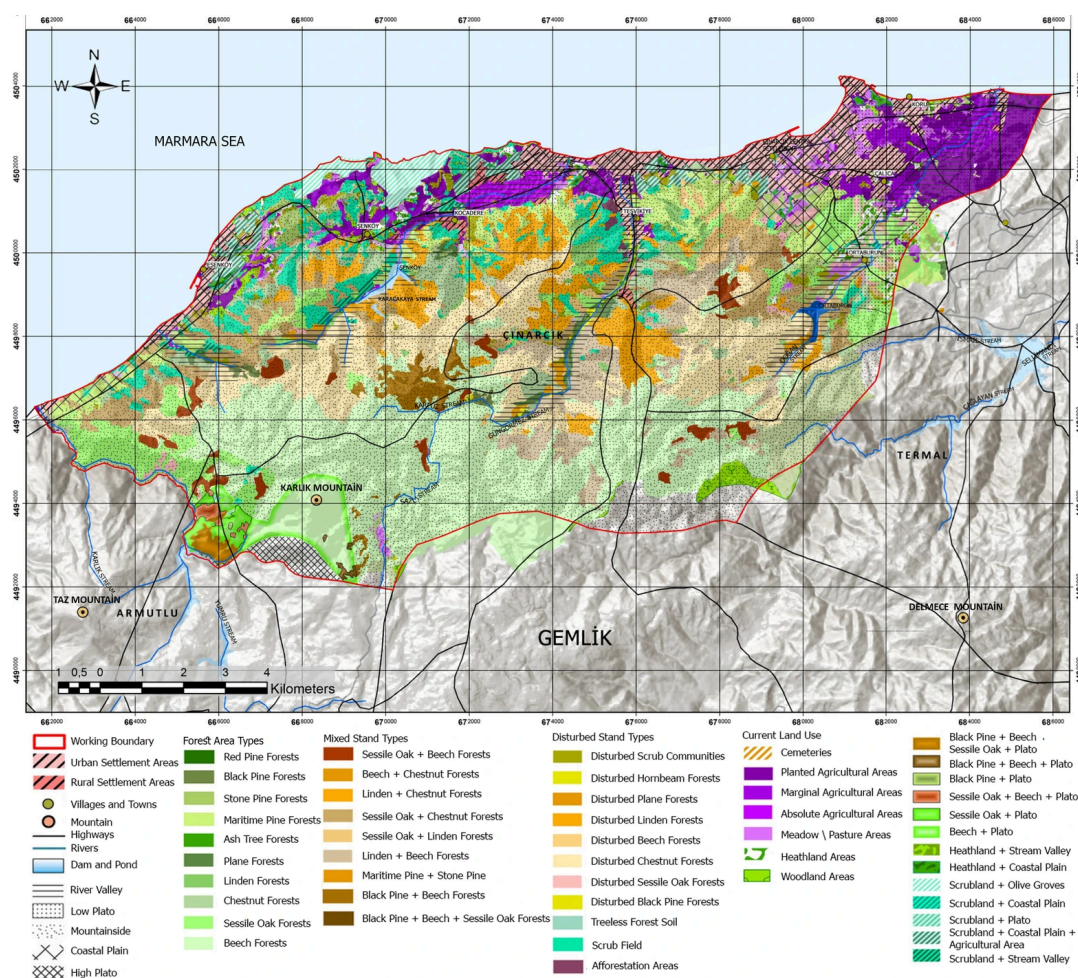


Figure 5. Distribution of the sub-biotope types in Çınarcık District (WGS 1984 UTM Zone 35N).

These findings indicate that beech-dominated plateau formations and maquis communities constitute the principal sub-biotope types of the study area, while the substantial proportion of disturbed biotopes—particularly maquis and sessile oak formations—points to the ongoing influence of anthropogenic pressures on forest structure and highlights priority areas for ecological restoration.

4. Discussion

4.1. Methodological Synthesis and Comparison with National and International Studies

The biotope mapping approach developed in this study is not a site-specific method but is based on a methodological synthesis developed through a comparative evaluation of thirty biotope mapping studies conducted in Türkiye and international biotope/habitat mapping approaches (Tables 2–4). International studies indicate that vegetation characteristics and field observations were initially the primary components in biotope identification, whereas contemporary approaches integrate these components with Geographic Information Systems (GIS), remote sensing, land cover datasets, and spatial analysis techniques [3,4,16]. Similarly, studies conducted in Türkiye demonstrate that vegetation, land cover, topographic characteristics, hydrological structure, and GIS-based analyses are the main components used for biotope identification. Therefore, biotopes should not be defined based on a single data group but rather through the integrated assessment of physiographic, biotic, and land-use-related indicators. The methodological framework developed in this research adopts this multi-criteria approach by integrating various data sources within a GIS environment and enabling the simultaneous evaluation of both main and sub-biotope types. Given its methodological basis in both Turkish and international literature, this framework is particularly transferable to other Mediterranean-transition coastal districts characterized by similar forest–agriculture–settlement mosaics, such as other parts of the Armutlu Peninsula or comparable Aegean and Marmara coastal areas exhibiting analogous physiographic and floristic conditions.

Although field observations (73.3%) and soil data (70.0%) were among the most frequently used indicators in the reviewed literature (Table 4), they were not incorporated as primary indicators in this study. Field observations were excluded because the present study relied on existing institutional datasets rather than a newly conducted systematic field survey, consistent with the approach adopted in a comparable proportion of national studies (Section 4.3). Soil data were excluded due to the unavailability of a sufficiently detailed, study-area-specific digital soil dataset at the time of analysis. It should be noted that frequency of use in the literature does not necessarily indicate ecological indispensability for a given study area; rather, indicator selection in this study was guided by the specific data availability, the dominance of forest and land-cover-driven biotope types in Çınarcık District, and the methodological consistency required for a transferable GIS-based framework.

4.2. Ecological Characteristics and Conservation Implications of Identified Biotopes

Consistent with the terminological clarification provided in Section 2.6, the biotope types discussed below are primarily defined through land cover, physiographic, and vegetation-structural indicators, with direct floristic evidence available mainly for forest biotopes.

The environmental characteristics of the study area, including physiographic conditions, microclimatic properties, floristic elements, land cover diversity, and habitat heterogeneity, have contributed to the formation of various biotope types. Approximately 60% of the study area consists of forest and agricultural lands, indicating a significant spatial dominance of semi-natural and managed ecosystems. Forest main biotopes are mainly concentrated in mountainous areas and on steep slopes, representing ecologically valuable

natural habitats. In terms of hydrological characteristics, stream networks and areas surrounding water resources were delineated as aquatic main biotopes based on hydrological features, land cover, and site conditions. Unlike forest biotopes, aquatic environments were not further classified into sub-biotope types because species-level aquatic vegetation inventories were beyond the scope of this study. These habitats represent sensitive ecological systems and are particularly vulnerable to anthropogenic pressures and pollution risks in areas close to settlements. Establishing protection zones around forest ecosystems and water resources and limiting land-use changes in these areas are recommended for biodiversity conservation and the maintenance of ecological functions [11].

Agricultural biotopes generally occur in flat and gently sloping areas, particularly in locations close to water resources, and they are important not only for regional agricultural production but also for maintaining landscape heterogeneity and ecological functions. These areas should therefore be considered as components of the landscape mosaic rather than merely as production zones. Grasslands, pastures, and shrublands also represent important habitats in terms of livestock activities and biodiversity conservation. Forest and wetland biotopes, which are more sensitive to environmental changes, should be considered priority areas for ecological protection. The structural complexity and species composition of mixed forest stands contribute to ecosystem resilience and highlight the importance of conserving broadleaved forest communities.

The contrast between short-rotation timber-production stands (30–120 years) and the uniformly long 200-year rotation period applied to ecologically and socioculturally oriented management classes reflects a management philosophy that prioritizes long-term ecological continuity over short-term timber yield in conservation-designated areas. Such extended rotation periods allow for the development of structurally complex, multi-layered stands that typically support greater habitat heterogeneity and species diversity compared to even-aged, short-rotation systems, thereby contributing to the maintenance of forest biodiversity at the landscape scale. Similarly, maquis areas—although administratively classified as forest land rather than forest stands—harbor a distinct assemblage of shrub and understory taxa that complements the tree-dominated biotopes identified in this study, further enhancing the overall structural and floristic diversity of the district.

Recognizing and maintaining such non-timber, biodiversity-relevant land-cover types within forest management frameworks is therefore essential for supporting landscape-scale biodiversity conservation objectives. The dominance of *Fagus orientalis* in both pure and mixed stands, as identified in Results, may be attributed to the region's humid microclimate and calcareous brown forest soils, which favor beech regeneration and competitive establishment over co-occurring species such as *Quercus petraea* and *Pinus nigra*. This ecological explanation is consistent with the species' well-documented preference for mesic, nutrient-rich sites across its Euro-Siberian distribution range.

In degraded forest and urban biotopes, silvicultural interventions conducted for fire, pest, and disease management should prioritize the conservation of rare and threatened species. The conversion of long-preserved natural forest areas into intensive recreational zones should be considered a potential threat due to the ecological pressures it may generate. In order to enhance urban biotopes, green infrastructure applications along roads and transportation corridors should prioritize native species adapted to regional ecological conditions and environmental stress factors. In this context, the conservation of fruit-bearing tree and shrub species important for wildlife, including *Sorbus domestica*, *Pyrus elaeagnifolia*, *Crataegus orientalis*, *Prunus domestica*, *Cerasus avium*, *Cornus mas*, *Corylus avellana*, *Rubus fruticosus*, *Arbutus unedo*, and *Pistacia terebinthus*, is recommended.

The identification and mapping of biotope areas contribute to the conservation of endemic plant species, habitat characteristics, and natural vegetation within the frame-

work of sustainability and nature conservation principles. In this regard, biotope maps represent important planning tools for landscape maintenance, ecological restoration, and conservation strategies. Similar to international practices, integrating biotope maps into urban and regional planning processes is essential for protecting ecological values and developing sustainable land-use decisions. Biotope mapping at urban and peri-urban scales provides guidance for green space planning, roadside vegetation management, and ecological rehabilitation practices, while improving the effectiveness of interventions based on potential natural vegetation. Currently, biotope mapping studies are largely conducted within scientific research projects and postgraduate studies. Despite their significant potential contribution to spatial planning processes, the absence of biotope mapping as a standardized planning instrument within the Turkish planning hierarchy remains an important limitation. Integrating biotope maps into conservation planning, ecological network development, and sustainable land-use strategies would strengthen their role as decision-support tools and contribute to more resilient landscape planning approaches.

4.3. Limitations and Future Research

A major limitation of this study is the absence of a newly conducted species-based field inventory; floristic data were instead obtained from İnan [14], a study conducted in 1994. This temporal gap is associated with the possibility that recent changes in species distributions, including potential shifts in invasive or range-expanding taxa, may not have been fully represented in the current classification. Nevertheless, the literature synthesis presented in Table 4 demonstrates that field observations are not a standardized component across all biotope mapping studies conducted in Türkiye (73.3%), and that approaches based on institutional datasets such as Forest Management Plans, CORINE land cover data, and TÜBİVES are commonly applied in studies conducted at comparable spatial scales [9,11,13].

The historical flora dataset was retained because no more recent systematic floristic survey of the Armutlu Peninsula exists; species records were used at the presence/location level rather than with precise georeferencing, and current land-cover boundaries were cross-checked against the Forest Management Plan rather than against the original 1994 survey extent. Taxonomic nomenclature was updated to current standards, but potential changes in invasive or range-expanding species since 1994 could not be assessed and are acknowledged as a limitation.

A related limitation concerns the absence of a formal accuracy assessment for the resulting biotope map. Although the Forest Management Plan [11] itself derives from a systematic field-based inventory, the boundaries of aquatic, agricultural, and urban biotopes in this study were delineated primarily through the integration of institutional datasets rather than through independent ground-truthing. Consequently, the classification accuracy of these biotope types could not be quantitatively validated. Similarly, the CORINE Land Cover dataset [9], despite its wide use in comparable studies, provides a relatively coarse spatial resolution for macro-scale land-cover classification, which may limit the precision of boundary delineation for smaller or transitional biotope units.

The study also focused primarily on floristic and vegetation-based indicators, without incorporating faunal or bioindicator data. Since biotope definitions conventionally encompass both plant and animal communities [1], the integration of wildlife distribution data in future applications would allow for a more comprehensive ecological characterization of the identified biotope types. Furthermore, the analysis represents a single temporal snapshot; it does not capture seasonal variation or longer-term land-cover and vegetation dynamics that may influence biotope boundaries over time.

Future research should therefore prioritize (i) updated, systematic floristic and faunal field surveys to validate and refine the current classification; (ii) formal accuracy assessment procedures, such as ground-truthing and confusion-matrix-based validation, to quantify the reliability of the biotope map; (iii) the integration of higher-resolution remote sensing data (e.g., Sentinel-2 or UAV-based imagery) to improve boundary precision for heterogeneous habitat types; and (iv) multi-temporal monitoring to assess the effects of land-use change and climate variability on biotope distribution. Applying the proposed methodological framework to additional case areas with differing ecological and administrative characteristics would further test its transferability and robustness as a standardized biotope mapping approach for Türkiye.

5. Conclusions

This study developed a GIS-based, multi-indicator biotope mapping model for Çınarcık District and identified four main biotope groups, namely forest, aquatic, agricultural, and urban biotopes, together with their associated sub-biotope types. The proposed framework integrates land cover, topographic characteristics, hydrological structure, forest stand data, and floristic information within a spatial analysis environment, providing a comprehensive approach for identifying ecological units at the local scale.

The results demonstrate that existing institutional datasets, including forest management plans, CORINE land cover data, TÜBİVES records, digital elevation models, and other GIS-based datasets, can provide an effective basis for a preliminary, inventory-based approach to biotope mapping when combined within a multi-layer spatial analysis framework [9,11,13]. Although the study relies on available floristic information rather than a newly conducted systematic field inventory, and the resulting classification has not undergone formal accuracy assessment, it provides a consistent and transferable methodological basis for landscape-scale ecological assessment.

The developed biotope map contributes to the identification of ecological values, conservation priorities, and sustainable land-use strategies by revealing the spatial distribution and characteristics of different habitat types. The integration of biotope mapping approaches into ecological planning processes in Türkiye can support nature conservation, green infrastructure development, and sustainable landscape planning practices. Future studies incorporating updated field observations and detailed species inventories will further improve the accuracy and applicability of biotope assessments.

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