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# Resilience of Mediterranean Forests to Climate Change

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Additional information is available at the end of the chapter

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## Abstract

In the Mediterranean region, forests play a key role in the welfare of urban and rural peoples, by providing highly appreciated marketed goods as well as high value but nonmarket services. Anthropogenic climate change entails a significant impact on Mediterranean forests, such as the reduced species diversity, high density, pest, and diseases. In this chapter, we present the achievements of the project LIFE ResilForMed (Resilience of Mediterranean Forests to climate change), as Sicilian responds on adaptation and mitigation to climate change: (i) map of Sensitivity Forest Areas to desertification of the Sicilian region; (ii) list of bird indicators showing sensitivity to desertification in Sicily; (iii) set of resilience indicators aimed to assess the resilience of Mediterranean forests to climate changes; (iv) list of sporadic and endemic tree species of Sicilian forests; (v) development of optimal management models suitable to improve or consolidate the resilience of forest and preforest ecosystems. This work is at the forefront of developing knowhow and transferable best management practices that may help Mediterranean forests to adapt to climate change and thereby, safeguard their multifunctional benefits for future generations.

**Keywords:** climate change, Mediterranean forests, adaptation strategy, resilience indicators, best management practices

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## 1. Introduction

Resilience is defined as the degree, manner, and pace of recovery of an ecosystem properties following natural or human disturbance [1, 2]. As such, it is a quantitative, process-specific measure (ecosystems are more or less resilient for a given variable), and not a generic,

qualitative property (ecosystems are not resilient or unresilient). Resilience is a quantitative property describing return to equilibrium and is hence only applicable to stable systems [3]. Mediterranean-type ecosystems have been documented as being highly resilient to disturbances [2, 4]. Recovery of ground cover after a disturbance of vegetation can be relatively fast, while time taken to return to a species composition similar to the initial one might be considerably longer [3]. For example, in different Mediterranean-type ecosystems, it has been observed that both grasslands [5] and shrublands [6, 7] return to their previous state in just a few years. On the other hand, other studies [8, 9] have found a slower tree recovery rate. The entire Mediterranean basin is characterized by landscape patterns with compositions resulting from countless, long, and complicated cultural and historical processes that developed in complex and varied environments [10–12]. In the Mediterranean region, a long history of natural (fire, floods, extreme droughts) and anthropogenic influences (overgrazing, forest harvesting, land use changes) have been the determining factors in shaping a mosaic of vegetation types with high ecological diversity and resilience.

In an environment such as the Mediterranean, forests play a key role in the welfare of urban and rural Mediterranean peoples, by providing highly appreciated marketed goods (e.g., firewood, cork, mushrooms) as well as high value but nonmarket services (e.g., soil protection and conservation, water regulation, recreation and landscape enhancement). The forests have been developing over thousands of years during which the climate has undergone significant changes. Phytocoenoses adapt to slow and constant changes, but anthropogenic climate change is faster and is not likely to allow ecosystems to adapt effectively: observed temperature increases and the occurrence of many serious problems for forest and preforest ecosystems, such as the reduced species diversity, high density, pest and diseases, threaten to make the adaptation more difficult. Forests have a dual function within climate change: they contribute to the mitigation of climate change, and their adaptation to climate change effects ensures their sustainable development under future site conditions [13].

The projections of climate change for 2016–2035 in Mediterranean Europe from the Intergovernmental Panel on Climatic Change (IPCC), estimate an increase in mean seasonal temperature up to 1.2°C in summer and 0.9°C in winter: mean seasonal precipitation is expected to increase by up to 25% in summer, but drop by up to 20% in winter [14]. This will cause a change in the distribution of the vegetation belts; moreover, extreme events such as flash floods, snowstorms, windstorms, fires, droughts, and heat waves are expected with increased frequency and intensity. The projections of the effects of climate change on European forests are complex: in Mediterranean basin, where water availability is a limiting factor, the most frequent summer droughts may lead to reduced productivity and lower resilience of forest.

Looking after the long-term future of forest resources, climate adaptation measures for forests became a high priority for the EU and its Member States. The European Union's new Forest Strategy noted the importance of both policy and practical actions suitable to improve or consolidate the resilience and adaptive capacity of forests. Particular attention in this respect is paid in setting up actions proposed by the European Union Strategy on Adaptation to Climate Change [15]. In view of the specific and wide ranging nature of climate change impacts on

the EU territory, adaptation measures need to be taken at all levels, from local to regional and national levels. A more climate-resilient environment is the overall purpose of the European Union Adaptation Strategy. This means improving the preparation and capacity to respond to the effects of climate change at local, regional, national, and continental levels, developing a coherent approach and improving coordination [15].

In this chapter, we present the achievements of the project LIFE ResilForMed (Resilience of Mediterranean Forests to Climate Change) co-financed by the EU, as Sicily responds on adaptation and mitigation to climate change. The project has mapped Sicily's forests to identify the most sensible areas for the desertification of risk, where urgent application of forest management techniques aimed at increasing resilience are needed. The bird communities susceptible to the desertification risk in Sicily were individuated too. ResilForMed has developed optimal management models for forest resilience, summarized in five forestry Best Management Practices (BMPs), which may be applied to other Mediterranean ecosystems as well as to other biomes. Finally, the project has involved local communities: (i) in forest protection measures and establishing indicators to define the role of communities and ecosystems in adapting to climate change; (ii) implementing the forest management models for fostering forest resilience through participatory tables; (iii) developing a forest governance model that consider the participation of lower level governments and the rural populations. The project ResilForMed is at the forefront of developing knowhow and transferable best management practices that may help Mediterranean forests to adapt to climate change and thereby safeguard their multifunctional benefits for future generations.

## 2. Forest resources in Sicily (Italy)

Sicily is the widest island of the Mediterranean basin and the broader Italian region (25711 km<sup>2</sup>). The region also includes smaller islands around the main one: the Aeolian archipelago, the Pelagian archipelago, the Aegadian archipelago, the islands of Pantelleria and Ustica. The island is characterized by huge variability in geological, climatic, and biological assets, and it is an expression of secular anthropogenic disturbances performed by various cultures and people that shaped the local landscapes and preserved an extraordinary biodiversity. From a geomorphological viewpoint, about 62% of the Sicilian surface is characterized by hills, about 24% can be ascribed to mountains, and about 14% to plains. Regional average annual precipitation is 679 mm, ranges from a minimum of about 450–500 mm in southern Sicily and subcoastal plains to about 1500–1700 mm in north-eastern mountain areas facing the sea. Regional average annual temperature is 16.4°C, ranges from 18–20°C near shorelines to 8–10°C in the highest mountain areas [16].

The agricultural systems characterize the Sicilian traditional landscape [17], including extensive active or abandoned farms, shrublands, pastures, and grasslands. Sicilian forests cover the slopes and the top of the main northern and north-eastern mountain ranges [18]. Sicily also has a large percentage of its forest surface protected by Regional Natural Parks (Mt. Etna, Madonie, Nebrodi, Sicani Mts. and Alcantara River), National Park “Isola di Pantelleria”, and

Natura 2000 network sites. Thus, forest and shrubland species composition and stand structure are typical of Mediterranean landscapes and exhibit a very high variability due to natural and anthropogenic influences [18–20]. In addition to these forest and preforest ecosystems (i.e., shrublands and woodlands), there are widespread reforested lands that are generally comprised of nonnative species, such as conifer and eucalypt plantations [18]. Sicily with its 274,454 ha of forests is one of the Italian regions with a lower coefficient of woodiness, about 10.6%, this forest surface increases to 512,121 ha if other wooded lands are taken into account [21]. It is known that historically forested areas were wider, with a loss of forest areas that lasted until the beginning of the last century, when this trend stopped and huge investments were done to reafforest wide cleared surfaces. The Sicilian forest and preforest hierarchical classification system includes 14 forest categories (level 1) and 58 forest types (level 2) divided in subtypes and/or variants (level 3) [22]. Categories are characterized by one or few dominant species (e.g., beech forest, downy oak forest, etc.) and/or main physiognomic type (i.e., forest, shrubland). Types are the reference unit homogeneous in floristic, ecological, management features. Subtypes identify a specific meso- and pedo-climatic conditions and/or silviculture practices, while the variants identify a specific species composition. A general view on the Sicilian forest and preforest classification system at the level of category is provided:

Beech (*Fagus sylvatica* L.) forests: the Sicilian beech forests cover 15,964 ha [22] and are of particular phytogeographic and ecological interest because they are located at the southernmost limit of the entire European distribution area of the species [23]. Beech grows from 1200 up to 2000 m a.s.l. on the ridges and high slopes of the Madonie and Nebrodi mountains, as well as on the slopes of Mount Etna. The category includes four forest types due to the ecological amplitude of this species in colonizing different substrates (i.e., calcareous, siliceous, volcanic). Traditionally, beech forests in Sicily were mostly managed as coppice for charcoal production. Today, these stands are used for occasional grazing and wood harvesting, resulting in highly diversified structures which cannot be easily classified as standard structural managing models (simple coppice, coppice with standards, or selection coppice).

Chestnut (*Castanea sativa* Mill.) forests: these stands cover 11,520 ha [22] and find their optimum habitat between 1000 and 1400 m a.s.l. by colonizing siliceous and volcanic substrates. However, chestnut forests extend to lower altitudes (400–500 m a.s.l.) on the slopes of north-eastern Sicily (Madonie, Nebrodi, and Peloritani Mts.). On the south-eastern slopes of Mt. Etna, chestnut spreads over the upper montane region where it reaches its highest altitude. The category includes a thermophile type and a mesophile one. Coppicing was the traditional management system to provide firewood, small and medium poles used in agriculture. Today, chestnut fruit production is dramatically reduced and is rather oriented toward high quality products in limited areas.

Cork oak (*Quercus suber* L.) forests: these stands cover 18,830 ha from sea level up to 500 m a.s.l. on the north (Madonie and Nebrodi Mts.) and south-east (Iblei Mts.) of Sicily, by colonizing siliceous and volcanic substrates [22]. Cork oaks are usually dominant in silvopastoral systems in many areas of Sicily, where trees were exploited alternately for cork production or firewood, the shrubby, and herbaceous layer were used for grazing and occasionally mushroom picking [24, 25].



Holm oak (*Quercus ilex* L.) forests: the evergreen holm oak forests represent the potential vegetation in more than half of Sicilian coastal and sub-coastal hills. Their extension is nowadays much more limited due to the historical spread of agriculture and forest harvesting. These stands cover 28,650 ha, include four forest types due to the ecological amplitude of this species in colonizing different environments with different plant communities [22]. On the island, holm oak is a key species in many primary and secondary formations from the sea level up to 1500 m a.s.l., forms pure and mixed forests. Regular and frequent coppicing of these stands was the traditional management system to provide firewood and charcoal. Today, following the cessation of coppicing and with stand aging, the stumps transformation into more homogeneous stand structures is increasing. Charcoal production, very important in the past, is practically disappeared.

Downy oak forests: these stands cover 84,753 ha, about 17% of the Sicilian forest surface, from sea level up to 1200 m a.s.l. on the slopes of north Sicily (Sicani, Madonie, Nebrodi and Peloritani Mts.), as well as on the slopes of east Sicily (Mt. Etna and Iblei Mts.) [22]. These stands include two main species: one is downy oak (*Quercus pubescens* Willd.), the other is sessile oak (*Quercus petraea* L.). The category include five forest types due to the ecological amplitude and maximized morphologic variability of downy oak driven by different climatic and edaphic conditions, ranging from xerophile to meso-xerophile coenoses and from calcareous to volcanic substrates. Traditionally, downy oak forests were managed as coppice for charcoal and firewood production, resulting in highly diversified structures which cannot be easily classified as standard structural managing models (simple coppice, coppice with standards, or selection coppice).

Turkey oak (*Quercus cerris* L.) forests: these stands cover 25,289 ha from 400 up to 1500 m a.s.l. on the slopes of Nebrodi Mts., only a few small nuclei are on Etna Mt. and Ficuzza Natural Reserve [22]. The category includes a thermophile type and a mesophile one: with regard to the first type, it is a Sicilian endemism (*Quercus gussonei* (Borzi) Brullo) exclusive to the Nebrodi Mts. and Ficuzza Natural Reserve. These stands are managed in two ways: coppice and high forests. The presence of uncontrolled grazing cattle and the competition with shrubs represent risk factors to natural regeneration of Turkey oak [26].

Orno-ostrietum forests: these stands include two main species, manna ash (*Fraxinus ornus* L.) and European hop-hornbeam (*Ostrya carpinifolia* Scop.), which form limited relict coenoses, about 100 ha, on the slopes of north-eastern Sicily (Nebrodi Mts. and Mt. Etna) [22]. The category includes a xerophile type and a meso-xerophile one.

Riparian vegetation: the category represents riparian formations along streams and rivers, which are characterized by highly variable intra- and inter-annual flow mainly resulting from variable in-flowing runoff. The category covers 19,177 ha [22], encompassing five forest types due to high variability in species richness, composition, and density. The most widespread species are African tamarisk (*Tamarix africana* Poir.), narrow-leafed ash (*Fraxinus oxycarpa* Bieb.), various willow species (i.e., *Salix alba* L., *Salix pedicellata* Desf., *Salix purpure* L., *Salix gussonei* Brullo & Spamp.), black poplar (*Populus nigra* L.), and oriental plane (*Platanus orientalis* L.).

Pioneer vegetation: these stands cover 4470 ha, from the sea level up to montane region on shallow and degraded soils, abandoned croplands, and rocky slopes. The category includes seven forest types for the high variability in specific species composition, structure, and evolutionary dynamics [22]. A Sicilian endemic species, Etna birch (*Betula aetnensis* Rafin), constitutes one type; other species are European aspen (*Populus tremula* L.), field elm (*Ulmus minor* Mill.), manna ash (*Fraxinus ornus* L.), black locust (*Robinia pseudoacacia* L.), ailanthus (*Ailanthus altissima* Mill.), Italian alder (*Alnus cordata* Loisel.), and acacia ssp.

Corsican pine (*Pinus nigra* ssp. *laricio* (Poir.) Mair) forests: these stands cover 4316 ha from 1000 up to 2000 m a.s.l. on the slopes of Mount Etna [22]. The category includes three forest types, ranging from xerophile to mesophile coenoses, depending to ecological drivers (elevation, soil type, and bioclimate) and anthropogenic factors. The ancillary species associated to Corsican pine at elevation up to 1500 m a.s.l are downy oaks, Turkey oak, and chestnut, while, at higher altitudes, beech, Etna birch, and other pioneer species (e.g., *Genista aetnensis* Raf., *Astragalus siculus* Biv., *Berberis aetnensis* C. Presl, *Juniperus hemisphaerica* J. Presl & C. Presl).

Mediterranean pine forests: it groups Mediterranean pine stands with high naturalness degree. These stands occupy limited extensions of the Sicilian forest landscape, above 2240 ha [22]. The category includes four forest types by colonizing different substrates (i.e., calcareous, siliceous, volcanic): the most common species are Aleppo pine (*Pinus halepensis* Mill.), stone pine (*Pinus pinea* L.), and maritime pine (*Pinus pinaster* Ait.).

Plantations: these stands cover 105,460 ha, about 21% of the Sicilian forest surface, from sea level up to the upper montane region [22], due to extensive afforestation program conducted by regional forest service after World War II. In terms of distribution, plantations are main constituted of *Eucalyptus* ssp., Mediterranean conifers (e.g., *Pinus halepensis* Mill., *Pinus pinea* L., *Pinus pinaster* Ait., *Cupressus* ssp., *Cedrus* ssp.) and mountain-Mediterranean conifers (e.g., *Pinus* ssp., *Cedrus* ssp., *Abies* ssp., *Pseudotsuga menziesii*). Afforestation has been based mainly on *Eucalyptus* ssp. and conifers because they are fast-growing species, and also because it was believed that this would lead to rapid restoration of soil hydrological processes and protective functions against soil erosion.

Mediterranean shrublands: these are large systemic units for the high variability of Mediterranean maquis, mainly grouped according to the most representative dominant species [27]. These are primary formations and/or developed from secondary successional processes on degraded preforest communities due to frequent fires or other anthropogenic actions. The category covers 108,570 ha, about 21% of the Sicilian forest surface and includes eight forest types, ranging from xerophile to meso-xerophile coenoses, colonizing different substrates (i.e., calcareous, siliceous, volcanic) [22]. The most widespread species are *Spartium junceum* L., *Pistacia lentiscus* L., *Calicotome infesta* (C. Presl) Guss., *Rhus* ssp., *Euphorbia* ssp., *Juniperus* ssp., *Cistus* ssp., *Quercus ilex* L., *Quercus calliprinos* Webb., *Olea europaea* var. *sylvestris* (Miller) Lehr, *Chamaerops humilis* L.

Supra-Mediterranean shrublands: these stands cover 30,730 ha in the supra- and oro-Mediterranean belt of island. These are primary formations and/or developed from secondary successional processes on shallow and degraded soils. The category comprises five forest

types, ranging from xerophile to mesophile coenoses, colonizing different substrates (i.e., calcareous, siliceous, volcanic) [22]. The most widespread species are *Erica arborea* L., *Ilex aquifolium* L., *Prunus* spp., *Rosa* spp., *Crataegus* spp., *Pyrus* spp., *Genista aetnensis* Raf., *Cytisus scoparius* (L.) Link.

The Sicilian forests can be considered at high risk of degradation for the growing phenomenon of forest fires and even more for the effects of climate change (e.g., flash floods, snowstorms, windstorms, droughts, and heat waves). Thus, climate changes may weaken or reduce forest and semi-natural ecosystems as well as exacerbate the potential desertification risk in Sicily, one of the Italian regions most threatened by this land degradation.

### 3. Climate resilience and adaptation strategy

Effective approach aimed at mitigating the effects of climate change to forest and preforest ecosystems of Sicily has involved a portfolio of different actions:

- i identification of areas at high risk to climate change at regional and landscape scale;
- ii analysis, assessment, and quantification of impacts of climate change;
- iii definition of the role of communities and ecosystems in the strategies of adapting to climate change;
- iv development of optimal management models suitable to improve or consolidate the resilience of forest and preforest ecosystems.

In order to identify the areas at high risk to climate change at regional and landscape scale, the environmental sensitivity areas (ESAs) to desertification of Sicilian region [28] and the Regional Forest [21] maps were overlaid, using the spatial analysis tools in a GIS environment. By this way, we developed sensitivity forest areas to desertification of the Sicilian region at a scale of 1:25,000. The different classes and sub-classes of sensitivity to desertification are distributed in a different way (**Table 1**). Regarding the results, the largest part of the Sicilian forest areas (49% of the area) was classified as “fragile” (mainly F2); 29% of the area was classified as “critical” (mainly C2), 17% as “potential”, and only 5% as “not affected.” More detailed results are shown in **Table 1**. The forest categories were also classified according to the level of sensitivity to desertification (**Figure 1**). The highest observed level of sensitivity (i.e., critical) was found in six forest categories (in decreasing percentage of land covered): Mediterranean shrublands, Riparian vegetation, Mediterranean pine forests, Pioneer vegetation, and Supra-Mediterranean shrublands that are, most likely, degraded successional stages of former Mediterranean forest types exposed to natural and anthropogenic stressors; on the other hand, the Turkey oak forests and beech forests showed the lowest level of sensitivity to desertification, suggesting the positive contribute of relatively stable forests for preventing desertification in Mediterranean region. Effective priority actions can be better planned if based on the knowledge of the degree of risk to desertification and the scale of the spatial

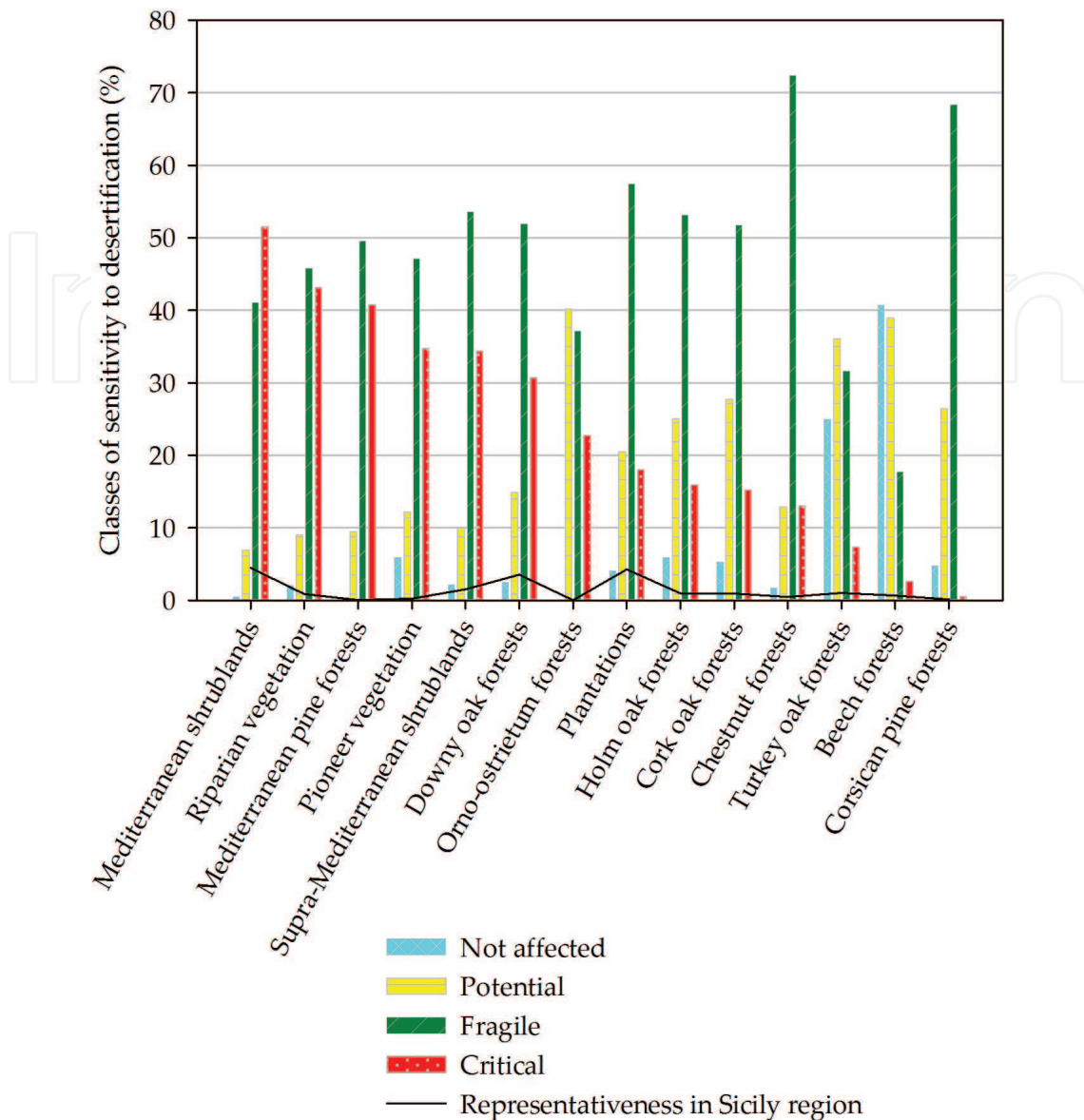


domains. The map of forest areas sensitive to desertification highlighted the relationships between conditioning factors as well as the identification of the priority areas of action, to implement the best forest management models. The priority areas of action were chosen using the following criteria [18]: (1) high level of sensitivity to desertification; (2) encompassed in a protected area, parks and/or Natura 2000 sites; (3) articulate samples of regional forest types; and (4) includes the presence of selected silvicultural practices. On this basis, one or two priority areas were chosen in each of the main forest territories (Sicani Mts., Madonie Mts., Nebrodi Mts., Mount Etna, the Calatino area, and Pantelleria Island) that are also considered to be the representative of main ecological and sociocultural variations of the entire island.

In order to assess and quantify the main effects of climate change, we performed a diachronic survey on identified priority areas through the photos/images interpretation of collected materials over a 57-year period (1955–2012), exactly in four ages: 1955, 1968, 1988, and 2012. The 1955 and 1968 surveys were performed by the Italian Military Geographic Institute (IGMI) using black and white film; the 1988 survey was performed by the Sicily Regional Territory Service with orthoimages; and for 2012, free satellite remote sensing images were exploited. For methods and data processing used, see Ref. [18]. Land use/land cover (LULC) changes were identified and quantified in the priority areas over time by considering the whole period (1955–2012) and sub-periods (1955–1968, 1968–1988, 1988–2012). Land use (LU) changes were ranked according to three classes [18]: (i) “unvaried” was given to the forest surfaces where no change had happened over time; (ii) “evolution” was given to the forest surfaces where successional dynamics resulted in a more complex structure or composition of the forest and preforest ecosystem; and (iii) the rank “degradation” included regressive dynamic cases with a clear simplification of structure and composition of the forest and preforest ecosystem. Land cover (LC) changes were also investigated and four classes of change were identified [18]: “unvaried”; “less significant,” where the change in observed LC was less than or equal to 20%; “increase” or “decrease,” where a progressive or regressive change, respectively, of over 20%

Sensitivity class	Sensitivity sub-class	Description	Forest areas (ha)	Forest areas (%)
Not affected		Areas non threatened	25,368.13	5.2
Potential		Areas threatened under climate and land use/land cover changes	81,908.48	16.7
Fragile	F1	Areas in which any changes in the delicate balance of natural and human activities is likely to bring	82,015.64	16.7
	F2		10,3607.96	21.1
	F3		53,825.26	11.0
Critical	C1	Areas already degraded through past actions, showing a threat to the environment of the surrounding lands	39,097.44	8.0
	C2		89,053.35	18.1
	C3		16,141.68	3.3

**Table 1.** Classification and distribution of Sicilian forest areas in terms of sensitivity to desertification.



**Figure 1.** Classifications of forest categories according to the level of sensitivity to desertification in Sicily region.

was recorded for LC. The 20% threshold is considered the minimum significant value that can detect regressive or progressive LC changes: it was chosen on the basis of a general overview of this type of phenomenon observed in Sicilian forests, together with the general knowledge of forest stand cover dynamics according to the mean Mediterranean climatic and ecological driving factors [29, 30].

The role of bird community and forest ecosystems in the strategies of adapting to climate change was analyzed on identified priority areas. Focusing on the bird communities, a generalized linear modeling (GLM) approach has been used. This model allows to analyze the effect of different variables with a high elasticity and is therefore widely used in the ecological analysis [31]. According to the approach chosen, 37 bird indicators were tested to assess sensitivity to desertification. For more details of methods used, see Ref. [32]. As result, a total

of 22 indicators (3 community indicators and 19 bird species) were highlighted as presenting sensitivity to desertification (**Table 2**).

With regard to forest ecosystems, we suggested a set of qualitative and quantitative indicators with the aim to assess the resilience of Mediterranean forests to climate changes. Thus, resilience indicators are of crucial importance because they can be used for a variety of purposes, such as: (i) describe and assess the state of the forests; (ii) identify pressure conditions within forests; (iii) assess the effects of forest management on forest composition, structure and functioning, discriminating among alternative policies, forecast future trends. An extensive field campaign on the unvaried areas, where no LULC change had occurred in the period 1955–2012, was set up to measure and calculate the resilience indicators. In particular, 12 forest types and 8 forest categories of Sicily were selected to define effective resilience indicators

EURING code	Indicator	P
	Species richness <i>sensu lato</i>	0.000
	Species richness <i>sensu stricto</i>	0.000
	Woodiness Bird Community Index	0.000
6700	<i>Columba palumbus</i>	0.001
8760	<i>Dendrocopos major</i>	0.000
10660	<i>Troglodytes troglodytes</i>	0.002
10990	<i>Erithacus rubecula</i>	0.000
12020	<i>Turdus viscivorus</i>	0.002
12650	<i>Sylvia cantillans</i>	0.000
12770	<i>Sylvia atricapilla</i>	0.012
13110	<i>Phylloscopus collybita</i>	0.064
13150	<i>Regulus ignicapilla</i>	0.000
14610	<i>Periparus ater</i>	0.060
14620	<i>Cyanistes caeruleus</i>	0.000
14790	<i>Sitta europaea</i>	0.030
14870	<i>Certhia brachydactyla</i>	0.000
15080	<i>Oriolus oriolus</i>	0.010
16360	<i>Fringilla coelebs</i>	0.000
16490	<i>Carduelis chloris</i>	0.001
16530	<i>Carduelis carduelis</i>	0.000
18580	<i>Emberiza cirrus</i>	0.000
18600	<i>Emberiza cia</i>	0.005

**Table 2.** List of bird indicators showing sensitivity to desertification in Sicily and the observed significance level (P-value).

and quantify the local threshold values of some indicators such as dendrometric parameter (i.e., the minimum level required to maintain the resilience and adaptive capacity of forests). For more details of methods used, see Ref. [33]. The following resilience indicators were selected and deemed effective:

1. Tree composition.
2. Forest crown cover.
3. Dendrometric parameters. The following parameters were measured: tree density ( $n \text{ ha}^{-1}$ ), basal area ( $G$ , in  $\text{m}^2 \text{ ha}^{-1}$ ), mean tree diameter ( $D_m$ , in cm), mean tree height ( $H_m$ , in m), stem volume ( $V$ ,  $\text{m}^3 \text{ ha}^{-1}$ ). **Table 3** offers an overview of the minimum level required to maintain the resilience and adaptive capacity of forests of every parameter for each forest type investigated.
4. Structural diversity: vertical and horizontal distribution.
5. Presence/absence of sporadic and/or endemic tree species.
6. Presence/absence of old-growth trees.
7. Presence/absence of natural regeneration: composition, seedlings and saplings density, limiting factors.
8. Presence/absence of deadwood (woody debris, standing dead trees, and stumps woody debris): volume and decay class.
9. Presence/absence of hydrogeological instability phenomena.

In addition, the field campaign allowed to identify and lists the sporadic and endemic tree species as an important element of the biodiversity and resilience of Sicilian forests. A sporadic tree species is a kind of species that is seldom found in the forest ecosystem in a well-defined region. This specific definition contains an important aspect: it is always important to take in consideration the contest where such species live to evaluate their sporadic nature, both in the absolute and relative meaning of the term. On the other hand, an endemic tree species is a kind of species that live only in one geographic region closely adapted to its particular environment (e.g., large or small areas, islands). Nevertheless these species, being sporadic and/or endemic, are less competitive than the dominant ones. For these reasons, we must protect and widespread them as well as enhance their value and presence. The list of sporadic and endemic tree species is given in **Table 4**.

Data collecting, analyzing, and monitoring of selected resilience indicators were needed to develop optimal management models for improving or strengthening the resilience of Mediterranean forest ecosystems. The test was restricted to 12 forest types listed in **Table 3** on sample plots. It was adopted that a rigorous methodological approach to evaluate objectively the current condition and the optimum of the investigated forest types (**Figure 2**): taking into account the optimal conditions to ensure good forest resilience, we evaluated as the current condition deviates from the optimum. Then, we estimated the forest dynamics in the short

Forest category	Forest type	Species	Tree density (n ha <sup>-1</sup> )	Basal area (m <sup>2</sup> ha <sup>-1</sup> )	D <sub>m</sub> (cm)	H <sub>m</sub> (m)	V (m <sup>3</sup> ha <sup>-1</sup> )
Downy oak forests	<i>Quercus pubescens</i> forest of xeric environments	<i>Quercus pubescens</i>	1241	19	14	7	98
Cork oak forests	<i>Quercus suber</i> forest of xeric environments	<i>Quercus suber</i>	573	9	14	5	29
Holm oak forests	Mountain <i>Quercus ilex</i> forest of carbonatic substrata	<i>Quercus ilex</i>	608	30	25	13	169
	<i>Quercus ilex</i> forest of xeric environments, variant of volcanic substrata	<i>Quercus ilex</i>	477	13	19	11	70
Turkey oak forests	<i>Quercus cerris</i> forest tipica	<i>Quercus cerris</i>	1050	28	18	14	168
Beech forests	<i>Fagus sylvatica</i> forest tipica on calcareous substratum	<i>Fagus sylvatica</i>	4042	36	11	10	207
	<i>Fagus sylvatica</i> forest tipica on siliceous substratum	<i>Fagus sylvatica</i>	1750	36	16	10	220
Corsican pine forests	<i>Pinus laricio</i> forest tipica	<i>Pinus nigra</i> ssp. <i>laricio</i>	859	38	24	14	287
Mediterranean pine forests	<i>Pinus pinaster</i> forest	<i>Pinus pinaster</i>	2896	55	16	10	356
Plantations	<i>Eucalyptus</i> plantation tipica	<i>Eucalyptus camaldulensis</i>	827	19	17	12	105
	<i>Eucalyptus</i> plantation, variant mixed with Mediterranean evergreen species	<i>Eucalyptus camaldulensis</i>	198	7	21	12	36
	<i>Pinus halepensis</i> plantation	<i>Pinus halepensis</i>	198	28	42	16	257

**Table 3.** Minimum level of main dendrometric parameters required to maintain the resilience and adaptive capacity of 12 Sicilian forest types.

and medium term in the absence of interventions and, in case of stagnation or regression, it was defined the most appropriate adaptation strategy.

Under this approach, we developed the optimal management models to be applied in relation to forest category (or type), summarized in five forestry Best Management Practices (BMPs) suitable to improve or consolidate the resilience of Sicilian forest and preforest ecosystems:

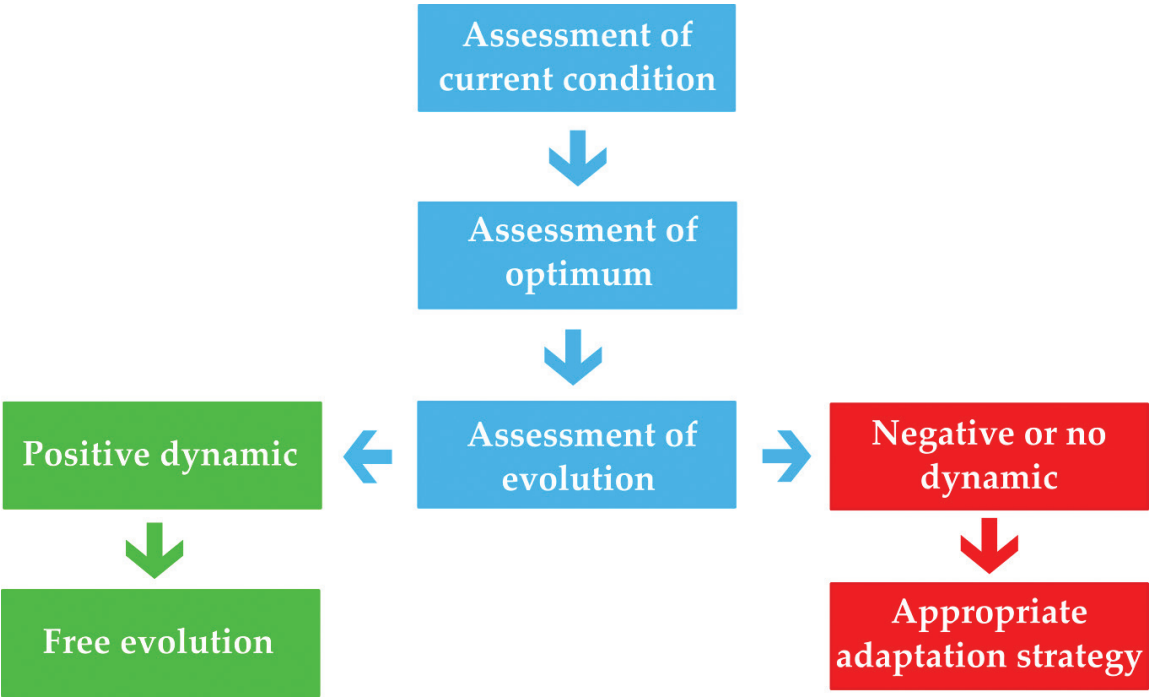
BMP1. Actions favoring mixing of species and hydrogeological stability of forests: practices in order to favor of species improving soil quality (nutrients, texture, and structure),



Scientific name	Common name (in Italian)	Endemic	IUCN Red List
<i>Acer monosperulatum</i> L.	Acero minore		
<i>Acer obtusatum</i> Willd et K.	Acero etneo		
<i>Acer pseudoplatanus</i> L.	Acero di monte		
<i>Betula aetnensis</i> Raf.	Betulla dell'Etna	Sicily, Mt. Etna	
<i>Carpinus orientalis</i> Miller	Carpino orientale		
<i>Celtis tournefortii</i> subsp. <i>asperrima</i> (Lojac.) Raimondo & Schicchi	Bagolaro dell'Etna	Sicily, Mt. Etna	Vulnerable (VU)
<i>Celtis australis</i> L.	Bagolaro		
<i>Ceratonia siliqua</i> L.	Carrubbo		
<i>Cercis siliquastrum</i> L.	Albero di Giuda		
<i>Fraxinus angustifolia</i> subsp. <i>oxycarpa</i> (Willd.) Franco & Rocha Afonso	Frassino meridionale		
<i>Genista aetnensis</i> (Raf. ex Biv.) DC.	Ginestra dell'Etna	Sicily, Mt. Etna; Sardinia	
<i>Ilex aquifolium</i> L.	Agrifoglio		
<i>Malus sylvestris</i> Miller	Melo selvatico		
<i>Ostrya carpinifolia</i> Scop.	Carpino nero		
<i>Pinus nigra</i> subsp. <i>laricio</i> Poirlet	Pino laricio	Sicily, Mt. Etna; Calabria	Vulnerable (VU)
<i>Pistacia terebinthus</i> L.	Terebinto		
<i>Prunus avium</i> L.	Ciliegio		
<i>Prunus mahaleb</i> L. subsp. <i>cupaniana</i> (Guss.) Arc.	Ciliegio canino di Cupani	Sicily	Vulnerable (VU)
<i>Pyrus spinosa</i> Forssk.	Pero mandorlino		
<i>Pyrus castribonensis</i> Raimondo, Schicchi & Mazzola	Pero di castelbuono	Sicily, Madonie Mts.	Vulnerable (VU)
<i>Pyrus pyraister</i> (L.) Burgsd	Pero selvatico		
<i>Pyrus sicanorum</i> Raimondo, Schicchi & Marino	Pero sicano	Sicily, Sicani Mts.	Endangered (EN)
<i>Pyrus vallis-demonis</i> Raimondo & Schicchi	Pero di Valdemone	Sicily, Nebrodi Mts.	Endangered (EN)
<i>Sorbus aria</i> (L.) Crantz	Sorbo montano		
<i>Sorbus aucuparia</i> L.	Sorbo selvatico		
<i>Sorbus aucuparia</i> L. subsp. <i>praemorsa</i> (Guss.) Nyman	Sorbo degli uccellatori	Sicily; Sardinia; Corsica	Vulnerable (VU)
<i>Sorbus domestica</i> L.	Sorbo domestico		
<i>Sorbus graeca</i> (Spach) Kotschy	Sorbo meridionale		

Scientific name	Common name (in Italian)	Endemic	IUCN Red List
<i>Sorbus torminalis</i> L. (Crant)	Ciavardello		
<i>Taxus baccata</i> L.	Tasso		
<i>Tilia platyphyllos</i> Scop.	Tiglio nostrale		
<i>Ulmus glabra</i> Hudson	Olmo montano		
<i>Ulmus minor</i> Mill.	Olmo minore		
<i>Ulmus minor</i> subsp. <i>canescens</i> (Melville) Browicz & Ziel.	Olmo canescente		
<i>Zelkova sicula</i> Di Pasquale, Garfi & Quézel	Zelkova siciliana	Sicily, Iblei Mts.	Critically Endangered (CR)

**Table 4.** List of sporadic and endemic tree species of Sicilian forests.



**Figure 2.** Flowchart of applied methodology to evaluate the current condition and the optimum of Sicilian forest types for defining adaptation strategies to climate changes.

which at the same time ensure or maintain adequate levels of organic matter in the soil, ensuring the improvement of water supply and the same conditions of light and temperature favorable to the acceleration of progressive successional forest dynamics.

BMP2. Renaturalization of forest plantations: interventions aimed to pander renaturalization processes with the aim of increasing the stability and thus the efficiency of ecological-structural ecosystem. Interventions to reintegrate native species in forests free of seed-bearing trees were also foreseen.

BMP3. Remedial measures and restoration of degraded forests: silvicultural actions on degraded woods due to fire, extreme droughts, overgrazing, erosion, land use changes, aimed at recovering the forest ecosystems.

BMP4. Actions aimed at enhancing complex structural forests: (i) conversion of coppices into high forests within the protected areas, in order to create communities with greater productivity and ecosystem stability; (ii) to create favorable conditions for sporadic tree species, the application of methods of management system that take care of the global needs of the forest and of each single species were foreseen, such as the tree-oriented silviculture techniques. Tree-oriented silviculture is based on targeted interventions aimed to advantage only some selected trees (target trees) and it makes possible focusing the efforts mainly on such aspects as the species mixture, stand structure, regeneration, and intra/inter specific competition dynamics.

BMP5. Actions favoring connectivity in agroforestry systems: forest interventions aimed at reducing the fragmentation of forest areas in order to increase connectivity and reduce the influence of anthropogenic activities in the surrounding areas (agricultural lands, pastures).

In particular, the BMPs were implemented in a set of forest interventions for nine forest categories on 120 ha of forest areas in Sicily (**Table 5**).

Forest category	Forest type	BMP	Forest interventions
Downy oak forests	<i>Quercus pubescens</i> forest of xeric environments	03	(a) Salvage felling of fire degraded downy oak forests
			(b) Introduction of native oak species in stands lacking of seed-bearing trees
			(c) Reducing forest fuel loads to decrease wildfire risk
			(d) Grazing exclusion
Cork oak forests	<i>Quercus suber</i> forest of xeric environments	01	Bio-engineering technique for soil erosion control
		02	Removal of exotic species
		03	(a) Salvage felling of fire degraded downy oak forests
Holm oak forests	Mountain <i>Quercus ilex</i> forest of carbonatic substrata	04	(b) Introduction of native oak species in stands lacking of seed-bearing trees
			(c) Reducing forest fuel loads to decrease wildfire risk
	<i>Quercus ilex</i> forest of xeric environments, variant of volcanic substrata	02	(d) Grazing exclusion
			(a) Conversion of coppices into high forests
			(b) Tree-oriented silviculture techniques
			(a) Removal of exotic plantations
			(b) Introduction of native oak species in stands lacking of seed-bearing trees
			(c) Grazing exclusion

Forest category	Forest type	BMP	Forest interventions
Turkey oak forests	<i>Quercus cerris</i> forest tipica	04	(a) Conversion of coppices into high forests (b) Tree-oriented silviculture techniques
Beech forests	<i>Fagus sylvatica</i> forest tipica on calcareous substratum	04	(a) Conversion of coppices into high forests (b) Tree-oriented silviculture techniques
	<i>Fagus sylvatica</i> forest tipica on siliceous substratum	01	(a) Introduction of native tree species (b) Bio-engineering technique for soil erosion control (c) Grazing exclusion
Corsican pine forests	<i>Pinus laricio</i> forest tipica	02	Removal of exotic plantations
Mediterranean pine forests	<i>Pinus pinaster</i> forest	04	Selective thinning on <i>Pinus pinaster</i> to reduce interspecific competition
Plantations	<i>Eucalyptus</i> ssp. plantation tipica	02	(a) Selective thinning on <i>Eucalyptus</i> spp. (b) Cutting all resprouts of <i>Eucalyptus</i> spp. stumps (c) Introduction of native tree and shrub species
		05	Establishment of wooded strips with native tree and shrub species as ecological corridors
	<i>Eucalyptus</i> ssp. plantation, variant mixed with Mediterranean evergreen species	02	(a) Selective thinning on <i>Eucalyptus</i> spp. (b) Cutting all resprouts of <i>Eucalyptus</i> spp. stumps (c) Introduction of native oak species in stands lacking of seed-bearing trees
	<i>Pinus halepensis</i> plantation	02	(a) Selective thinning on <i>Pinus halepensis</i> to reduce interspecific competition (b) Introduction of native tree species
		03	Reducing forest fuel loads to decrease wildfire risk
		05	Establishment of wooded strips with native tree and shrub species as ecological corridors
	Mixed coniferous plantation	02	Removal of exotic species
Mediterranean shrublands		03	(a) Salvage felling of fire degraded maquis (b) Introduction of native tree and shrub species (c) Reducing forest fuel loads to decrease wildfire risk

**Table 5.** Set of forest management interventions for each forest category (or type) suitable to improve or consolidate the resilience of 9 forest categories in Sicily.

All these developments have been addressed in drafting of the “Guidelines for assessing the Resilience of Mediterranean Forests to Climate Change”, forthcoming publication. This publication sets out the specific actions that policymakers, forest managers, and other stakeholders should take to improve or consolidate the resilience of forest and preforest ecosystems in Sicily and in Mediterranean Region. In this way, we suggested an approach to conserve biodiversity, to maintain resilience, and to give Mediterranean forest systems the best possible chance of adapting to climate changes.

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