LIFE+ PROGRAMME
Environmental Policy & Governance
PROJECT LIFE08 ENV/GR/000554

AdaptFor
"Adaptation of forest management to climate change in Greece"

Guidelines for the adaptation of forest management to **climate change** in Greece

THE GOULANDRIS NATURAL HISTORY MUSEUM
GREEK BIOTOPE/WETLAND CENTRE

MINISTRY OF ENVIRONMENT ENERGY & CLIMATE CHANGE
Forest Service
Directorate General for the Development and Protection of Forests and Rural Environment

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The present publication has been prepared in the framework of the LIFE08 ENV/GR/000554 Project "Adaptation of forest management to climate change in Greece" (www.life-adaptfor.gr), implemented by the Greek Biotope/Wetland Centre (Coordinating Beneficiary) and the Directorate General for the Development and Protection of Forests and the Rural Environment/Ministry of Environment, Energy and Climate Change (Associated Beneficiary) in cooperation with the Forest Directorate of Pieria and the Forest Services of Kalampaka, Parnitha and Sparti. The Project was co-funded by the LIFE financial instrument of the European Community, the Coordinating and Associated Beneficiaries.

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Emeritus Professor Sp. Dafis, having significant knowledge of the Greek forests, scientifically guided the LIFE+ AdaptFor Project. His contribution has been priceless. This publication is dedicated to his memory.

Beech forest in Rodopi, NE Greece
EKBY Photo Archive/L. Logothetis

The effects of forests to communities are so many and valuable that even if there were no forests we should have to invent them. We do have forests but unfortunately we keep on destroying them.

Wood, one of the main forest products of direct financial value, can be imported from other countries, if we can afford that. However, we could not import the benefits forests offer to people, such as water regulation, aesthetic and health effects, biodiversity conservation and so many others, no matter how much money we could afford.

The forests left must be well preserved, protected, improved and expanded.

Sp. Dafis

working group

The present publication is the result of a collective effort of the Working Group of the Project LIFE+ AdaptFor "Adaptation of forest management to climate change in Greece". The scientific personnel of the Greek Biotope/Wetland Centre (EKBY) and of the Directorate General for the Development and Protection of Forests and Rural Environment implemented the actions with the help of experts and in cooperation with the Forest Services in the four pilot areas.

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Mixed forest in Rodopi, NE Greece
EKBY Photo Archive/L. Logothetis

Birch forest
EKBY Photo Archive/M. Katsiakiori

Orchid
EKBY Photo Archive/L. Logothetis

Mullein
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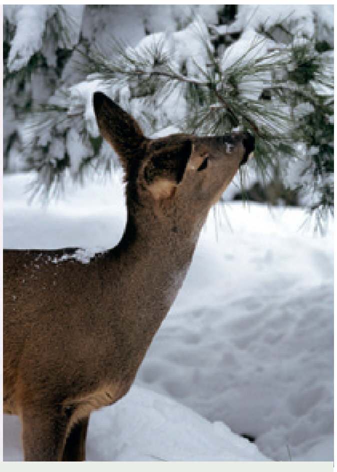
EKBY Photo Archive/L. Logothetis



Young roe deer
EKBY Photo Archive/S. Milionis

1 Introduction

The impact of climate change on forest ecosystems is expected to be direct (e.g. reduction of productivity and weakening of trees due to increased drought) or indirect (e.g. deterioration of forest health due to pathogens' outbreaks). As a result, the achievement of both the management objectives and the services[1] that forests provide to people are under threat.

Up to now, the management of Greek forests has being carried out without taking into consideration the changing climate conditions and the vulnerability of forests to them. However, from now on, the competent Forest Services should adapt their management objectives and practices in order to preserve the health and productivity of forests under current and future climate and environmental conditions. Adaptation of forest management to climate change aims at the reduction of forest vulnerability and at the increase of their resilience[2], while at the same time benefits may arise in the field of climate change mitigation [increase in the sequestration and storage capacity of carbon dioxide (CO_2) in forests].

1. The term "ecosystem services" describes the processes and functions that are provided by the ecosystems and benefit people. The services provided by natural ecosystems are divided into four categories: a) provisioning, such as the production of food, fuel, wood etc, b) regulating, such as water and climate control c) supportive, such as preservation of soil fertility and nutrients cycle, d) cultural, such as education, ecotourism and recreation.

2. The resilience of an ecosystem refers to the amount of disturbance that an ecosystem may absorb before it turns to a new equilibrium state, characterized by a different structure (Gunderson and Holling 2002, *from* Brand and Jax 2007).

However, due to the fact that the uncertainties regarding the future climate conditions are still numerous (especially at local level the predictions given by climate models are neither considered safe nor precise), Forest Services are asked to design and implement measures of "no or low-regret" which meet a wide range of potential climate changes and comply with good silvicultural practices in the context of sustainable forest management. Adapting forest management requires Forest Services to obtain new knowledge and skills for their every day practice. In the light of climate change, cooperation between science and management is needed, so that Forest Services increase their capacity in subjects, such as the assessment of forest vulnerability, the design and implementation of targeted forest management measures, the monitoring of climate change impacts and of the effectiveness of adaptation measures etc.

The present publication is addressed to the personnel of Forest Services, mainly to those responsible for forest management, and also to professionals who participate in forest management planning, students of relevant University Departments, mainly at local, but also at regional and national levels. However, as the impacts of climate change are wider, the contribution of researchers, non-governmental organizations and other stakeholders may be required for the drafting of adaptation proposals. Many climate change impacts (such as fires and pathogens' outbreaks) may exceed the competence limits of a local forest service due to their nature and extent or due to jurisdictional and cost issues, and therefore action may be required at regional or national level.

Beech forest
EKBY Photo Archive/L. Logothetis

Valia Kalda valley, Pindos mountain range
EKBY Photo Archive/K. Zisis

The purpose of the present publication is to enhance the capacity of the personnel of Greek Forest Services to detect the impacts of climate change in good time and then manage the forest ecosystems within their competence, accordingly. These adaptation guidelines are based on reports from international and national organizations, scientific publications and publications on forests and climate change, as well as on the results and deliverables of the LIFE+ AdaptFor Project Working Group. In particular, data from the publication "The forests of Greece" and FAO's approach regarding the categorization of climate change impacts and adaptation measures, specified for the Greek forests, were used.

In the following chapters, a brief description of the Greek forests (per forest vegetation zone), their functions (benefits to communities) and the threats they encounter are provided. Next, a specific reference on threats arising due to climate change is provided, as regards forest productivity, biodiversity, water regime, forest fires and pathogens. The main part of this publication includes a detailed description of the three steps required to adapt the management of Greek forests to climate change (vulnerability assessment, design and implementation of adaptation measures, monitoring-review). Following that, specific adaptation measures for forest management are proposed, categorized per a) forest function and b) Greek forest ecosystem (vegetation type). Finally, certain general measures are included. Below each step, a brief description of the approach adopted and demonstrated at four study areas in the framework the LIFE+ AdaptFor Project is provided (as a case study).

The
LIFE+ AdaptFor
Project

The key question that the Project LIFE+ AdaptFor addresses is *how to adapt forest management to climate change in Greece*. Particularly, the Project aims to demonstrate the approach of adapting forest management to climate change in four selected forest ecosystems, distributed throughout Greece (1. Ritini-Vria Forest on Mount Pieria in North Greece, 2. Aspropotamos-Kalampaka Forest in Thessaly, Central Greece, 3. National Park of Parnitha near Athens and 4. East Taygetos Forest in Peloponnisos, South Greece). In these forests, changes in vegetation attributed to climate change have already been observed. These study areas are State owned forests, managed by the Greek Forest Services and they are all located within NATURA 2000 Network sites.

In the framework of the Project, the vulnerability of four selected forest ecosystems has been assessed, in terms of forest health and vegetation changes, under the effects of climate change. The phenomena (the dieback of Scot pine and Greek fir due to pathogens' outbreaks and the invasion of conifers in broadleaved forests) and their development during the last decades have been associated to alterations of climate parameters recorded in these study areas (production of temperature and precipitation time series).

Mixed forest in Aspropotamos, Kalampaka, South Pindos
EKBY Photo Archive/L. Logothetis

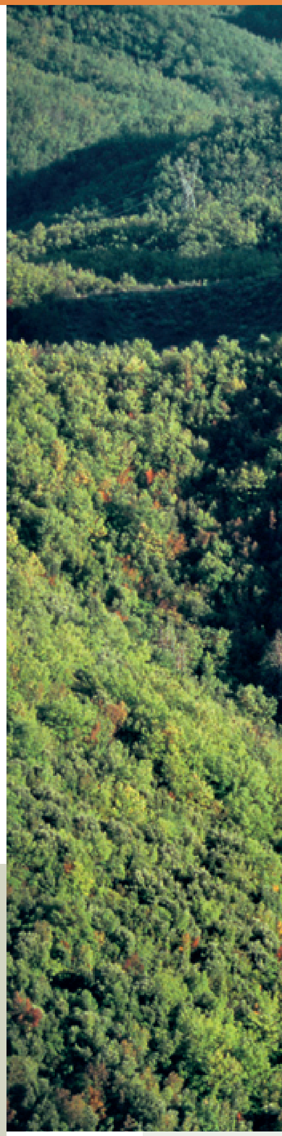
Field work
EKBY Photo Archive/L. Logothetis

Based on the results of the vulnerability assessment, measures to adapt forest management practices to climate change have been drafted for each of the four areas. The proposed adaptation measures have been finalized after consultation with the competent Forest Services, in order to increase applicability, in terms of cost and social acceptance. The proposed management measures are following on the "low or no-regret" adaptation approach, corresponding to a wide range of possible climate changes and aiming at the reduction of forest ecosystem vulnerability and at the strengthening of their resilience to climate change. They also include instructions on how to address emergency issues such as insect outbreaks, droughts etc. All measures have been further specialized at stand level and finally incorporated in the Forest Management Plans of the four study areas. Furthermore, a telemetric meteorological station and four permanent sampling plots per study area have been established in order to monitor climate and sylvicultural parameters and to assess the success of the implementation of adaptation measures.

Beyond the demonstration, the Project aimed also to enhance the capacity of Forest Services to early detect and respond to phenomena, which could be attributed to climate change. In this context, the guidelines in hand have been published and a Training Seminar has been held for the personnel of the Greek Forest Services.

Finally, the need for adaptation of forest management to climate change and the Project results are presented at the Project webpage (**www.life-adaptfor.gr**) and through other communication activities contributing to the dissemination of the Project aims and results.

2 The Greek forests



2.1. General information

Forests in Greece cover approximately 3.9 million ha, accounting for around 30% of the country's surface area. Greece does not boast a large forest area compared to Northern countries, however it exhibits a great diversity of forest ecosystems.

This diversity can be attributed to the flora richness and climate type variety (ranging from pure Mediterranean to pure continental), the mountain terrain (as Greece is mainly a continental country with 42 summits over 2,000 meters), the large variety of geological formations and rocks, the historical and cultural development and finally the financial and social structure of the country.

Mixed broadleaved forest
EKBY Photo Archive/L. Logothetis

Black pine forest
EKBY Photo Archive/L. Logothetis

Norway spruce seedlings
EKBY Photo Archive/L. Logothetis

Forest landscape in Chelmos, Peloponnese
EKBY Photo Archive/L. Logothetis

Forest cover in Greece

As stated in the Europe's Forests Report of 2011[3] (2010 figures), the forest area (forests and other wooded land) occupies 6,539,000 ha, i.e. slightly more than half of Greece's surface area (50.7%). Out of these, forests cover 30.2% (3,903,000 ha) and other wooded land cover 20.5% (2,636,000 ha).

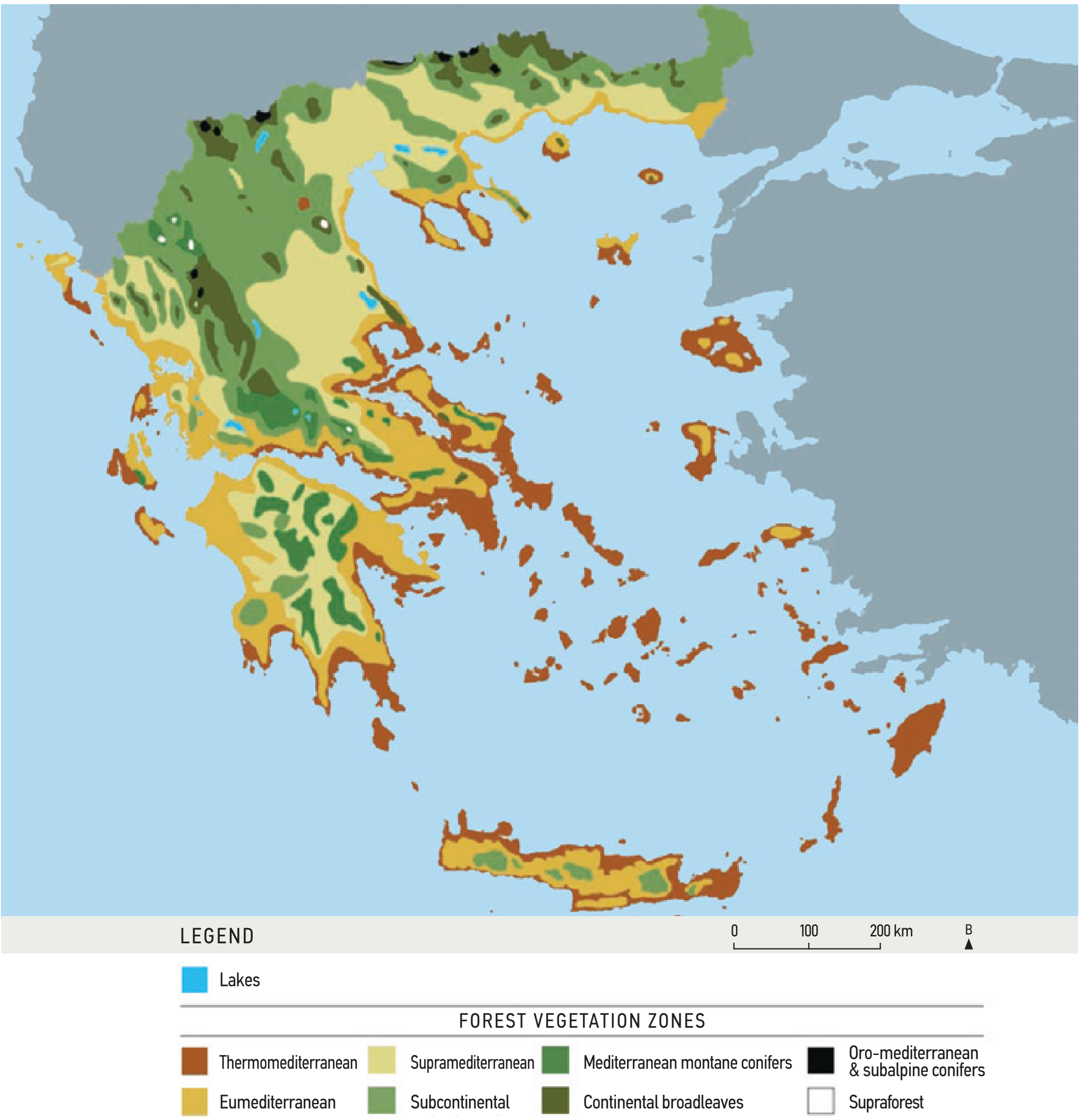
Data from the above report show that, in Greece, the forest surface area is almost stable during the years 1990-2010 (6,511,000, 6,525,000, 6,532,000 and 6,539,000 ha for years 1990, 2000, 2005 and 2010, respectively). During these 20 years, forest cover has increased (3,903,000 ha in 2010 compared to 3,299,000 ha in 1990), while the area of wooded land shows corresponding reduction (2,636,000 ha in 2010 compared to 3,212,000 ha in 1990). The increase of forest cover may be due to the fact that agricultural and livestock activities are abandoned on mountainous areas and, as a result, forest regenerates in the above abandoned rural and grassland areas.

The growing stock seems to have increased by 18% during the period 1990-2010 (from 156 x 10^6 m^3 in 1990, to 185 x 10^6 m^3 in 2010). Ninety two percent of growing stock is available for wood production (170 x 10^6 m^3).

3. FOREST EUROPE, UNECE and FAO. 2011. State of Europe's Forests 2011. Status and Trends in Sustainable Forest Management in Europe.

2.2. Forest vegetation zones[4]

With the effect of all the above parameters, five bioclimatic forest vegetation zones are developed in Greece (see map below). These are the Mediterranean, the supramediterranean subcontinental zone, the zone of Mediterranean montane conifers, the zone of temperate broadleaved deciduous forests and the zone of high Oro-mediterranean and subalpine conifers. Furthermore, a separate zone, the azonal riparian forests, forms in Greece, not closely depending on climate conditions but on the water regime.



4. *Adaptation from Dafis Sp.* 2010. The forests of Greece. The Goulandris Natural History Museum. Thessaloniki. 192 pages.

Stone pine forest in Strofylia, Peloponnese
EKBY Photo Archive/L. Logothetis

2.2.1. Mediterranean (Thermomediterranean-Eumediterranean) vegetation zone

This zone appears in an almost continuous band along the coasts of Western, Southeastern and Eastern Greece up to Mount Olympus and Mount Pieria, the Ionian and the Aegean Sea, the Dodecanese, Crete, Chalkidiki peninsula and along the coasts of Macedonia and Thrace. The altitude of this zone ranges from 100-300 m in Northern Greece and reaches 1,000-1,500 meters on the mountains of Crete.

The climate is purely Mediterranean, with spring-autumn and winter precipitations, warm summers and relatively mild winters. The dry season ranges from 2-3 months in North-Eastern Greece up to 6 months in Attica, East Crete and Cyclades.

In this zone, due to the mild climate and easy access to the sea, ancient civilizations such as the Minoan, the Mycenaean, and the Cycladic ones, as well as all big cities of Greece have been developed. Almost 80% of the population lives here, causing an early destruction and degradation of forests.

The forests of this zone are generally divided into forests or shrubs of evergreen broadleaves (palm forests, wild olive forests and shrubs, carob and mastic trees, Holm oak, laurel and heather forests, Kermes oak forests and shrubs) and into Mediterranean conifers (juniper forests, Aleppo and Aegean pine forests, Stone pine and Cypress forests). These maquis-type forests have been degraded in their largest part from high dense to low sparse shrubs and phrygana (a typical East Mediterranean zone of cushion-like spiny semifruticose shrubs). On the contrary, Mediterranean coniferous forests seem to be in a good status despite the pressures exerted on them due to human activities.

Strawberry tree, Kermes oak, Christ's thorn, Juniper
EKBY Photo Archive/L. Logothetis

2.2.2. Supramediterranean subcontinental zone (oak forest zone)

Over the zone of maquis-type forests and Mediterranean coniferous forests, extends a wide zone of deciduous broadleaved, mainly oak forests (Valonia oak forests, Cyprus oak, Macedonian oak, Downy oak, Hungarian oak, Balkan sessile oak, Turkey oak and Pedunculate oak) as well as chestnut forests. Oak forests extend on the hilly, sub-mountain and mountain area of the entire Central and Northern Greece (Epirus, West, Central and East Macedonia, Thrace, Chalkidiki, Thessaly), as well as in Central Greece, the Peloponnese, Evia, Crete and some Northeastern Aegean islands. Chestnut forests sporadically distribute throughout Central and North Greece, the Peloponnese, Evia, Lesvos, Crete; however their main distribution area includes Pilio, Ossa, Mavrovouni, Mount Athos, Northeast Chalkidiki, Pindos, South Olympus, Mount Pieria and Vermio. They sporadically appear throughout Central and Northern Greece, the Peloponnese and on Evia, Lesvos and Crete islands.

The climate of this zone is Mediterranean, however with more intense precipitations during autumn, winter and spring. The dry season is limited to 2-3 months. Temperatures during winter often fall below 0°C and precipitations are quite common. It is actually a transition from the Mediterranean to the subcontinental-continental climate.

Oak forests occupy slightly less than 50% of the country's forests. Oak forests have an important ecological, aesthetic, hydrological, protective, cultural and financial role. Moreover, their significance stems from: a) the large number of species they host, since, due to their wide ecological distribution range, they provide habitat to numerous trees, shrubs, grasses, lichens, mosses and fungi, as well as to large and small mammals, a great number of birds, reptiles and invertebrates and b) their large distribution area. However, nowadays, most oak forests have been converted into low coppice due to intensive management.

Chestnut forests, despite of their limited distribution (only 1% of the overall forest surface area), have great ecological and financial value, since they are among the most productive forests of Greece. They are managed as coppice for wood production and as high forests for the production of chestnuts. During the last years, chestnut forests suffer from two serious diseases: a) chestnut ulcer, caused by the fungus *Pseudonectria parasitica* which mainly affects the over-ground parts (trunk and branches) leading to its necrosis and b) inc disease which affects the tree root system.

Mixed broadleaved forest in Rodopi, NE Greece
EKBY Photo Archive/L. Logothetis

2.2.3. Zone of Mediterranean montane conifers

These are Greek and Bulgarian fir forests, Black pine forests and forests and shrubs of mountainous junipers. They extend in the sub-continental and the continental climate zones.

The Greek fir *(Abies cephalonica)* is a species endemic to Greece. It creates pure forests on Mount Taygetos and Parnonas, on Parnassos, Oiti, Timfristos and Oxia mountains, as well as on Evia and Kefalonia islands (Mount Ainos) after which the species was named. These are dense, uneven-aged forests usually of irregular structure and they have great ecological, aesthetic and protective value. Often, particularly in the Peloponnese, Greek fir is mixed with Black pine, beneath the canopy of which the species regenerates easily. Right after the long dry season and high temperatures of the period 1987-1988, Greek fir forests had been seriously affected due to bark beetle outbreaks. The main reason must have been the necrosis of their upper root system, due to drought and high temperatures, which led to the weakening of the trees.

Greek fir forest on Mount East Taygetos, Peloponnese
EKBY Photo Archive/L. Logothetis

2.2.4. Zone of temperate broadleaved deciduous forests

Further in the north and on higher altitudes, the climate is mountainous Mediterranean to continental and resembles to the climate of Central Europe. Winters are colder, summers are cooler, the amount of precipitation increases, the snow lasts several months and the dry season is limited to 1-1.5 months. In this zone, beech forests, but also yew and holly forests, dominate.

In Greece, the distribution of beech forests is patchy and they are found in Eastern, Northeastern, Northern and Northwestern slopes, occupying small or larger surface areas. These forests are mainly distributed: a) on the mountains of Northern Greece (Grammos, Voio, Verno, Varnountas, Voras, Paiko, Beles, Orvilos, Vrontou, Falakro, Kerdilia, Paggaio, Rodopi), b) in Central and Northeastern Chalkidiki (Cholomontas, Stratoniko) and at the peninsula of Mount Athos, c) on the mountain ranges of Eastern Greece (Pilio, Mavrovouni, Ossa, South Olympus, Olympus, Titaros, Pieria and Vermio mountains) and d) on the mountain range of South and North Pindos. The southernmost edge of beech forests is Mount Grammeni Oxia in Vardousia and the easternmost one is Treis Vrises in Derio, Evros. It usually forms high forests, either pure or mixed with other species, and more rarely (in Pilio, Chalkidiki etc.) low coppice forests. The pure or mixed beech forests are very productive and have a significant aesthetic and financial value. They provide habitat for large and small mammals and birds. Furthermore, thanks to the chemical properties of their leaves, they produce potable water of the best quality.

Yew is sporadically found in Macedonia, Thrace, Thessaly, Central Greece, rarely in the Peloponnese, Evia, Thasos, Samothrace etc. It is the most shade-tolerant forest species in Greece and grows in humid and cool soils, creating pure stands in the understory and middle level floor of beech forests, Bulgarian fir and more rarely Black pine. Yew is a slowly growing and one of the longest living forest species, since it lives over 2,000 years.

Holly is usually found in shrub form on the mountains of continental Greece, on the Ionian Islands, in Northeastern Chalkidiki, on Mount Athos, on the islands of Evia, Thasos etc. It is usually sporadically found in humid and northern slopes, in beech, fir and chestnut forests. It rarely forms pure stands (e.g. South Olympus-Kallipefki area, Evritania, Evia) which form a habitat type included in Annex I of the Habitats Directive (Directive 92/43/EEC). It may be used as an ornamental plant and its fruiting branches are used for Christmas decoration.

Beech forest in Rodopi, NE Greece
EKBY Photo Archive/L. Logothetis

2.2.5. Zone of high Oro-mediterranean and subalpine conifers

In Greece, this zone is found only on the high mountain ranges of Northern Greece (North Pindos, Olympus, Pieria, Vermio, Voras, Orvilos and Rodopi mountains). In this zone, the so-called "boreal" species appear, such as Norway spruce, Scots pine, Bosnian pine, Macedonian pine, birch and aspen. These species are adapted to very low temperatures and a relatively short growing period.

Scots pine in Greece occurs in its southernmost European distribution limits. It is found on Mount Pieria, Sarakatsana region, on North Pindos (Valia Kalda), on Vermio, Voras, Lailias, Orvilos and mainly on Western Rodopi mountains. Its distribution is limited as it occupies only ~2,000 ha in total, according to the first National forest inventory, and is considered to be a remnant of the glacial period. In a relatively small surface area, all of this forest tree species' forms and types of Central Europe, from thin trunk, thin branch and flexible trunk types of the Alpes, to stout wry trunks with wide canopy and stout branch types of lowlands, occur. Therefore, Scots pine forests in Greece may constitute a valuable gene pool for the entire Europe. However, in its thermal limits, on Mount Pieria, especially where it invaded as a pioneer species, in abandoned fields, Scots pine proved to be really vulnerable to infestation from the fungus *Peridermium pini* but also from bark beetles, which cause necrosis of the affected individuals within a short time period.

Scots pine forest on Mount Pieria, NC Greece
EKBY Photo Archive/L. Logothetis

Alder forest in Nestos river, NE Greece
EKBY Photo Archive/L. Logothetis

2.2.6. Azonal riparian forests

Riparian forests could be divided, based on species composition and the nature of their wood, into: a) softwood forests (willow, poplar, alder), mainly found along the banks of rivers or lakes on sandy soils with high groundwater and periodic flooding of large duration and b) hardwood forests (oak, ash, elm), found at a certain distance from banks, on heavier soils, with lower and fluctuating groundwater levels and periodic flooding of shorter duration.

Although they grow on infertile soils, these forests are very productive and exhibit high biodiversity, including a great number of woody climbers (vines), which create "riparian galleries". In addition, they play an important role in securing and protecting river banks and mountain streams from erosion.

However, riparian forests are vulnerable to anthropogenic activities. The main causes for the reduction of their distribution and for their degradation have been land clearings and land reclamation for agriculture or for other uses, as well as flood protection constructions (alignment of river banks), creating embankments and preventing floods and as a side-effect decreasing fertilization, especially in deltas.

2.3. Forest functions

2.3.1. General information

Up to a few decades ago, Greek forests have been mainly known to the general public due to their financial value, i.e. as "producers" of wood for several uses. Today, forests are known to serve numerous other objectives and have a number of functions and services they offer to humans, so wood production comes in second place: water regulation, i.e. control of the runoff and quality of produced water, protection of soil from erosion, wind protection, their impact on climate factors, the effect in air quality, as well as the aesthetic, recreational and health benefits gain ground and importance. All the above, combined with the importance of forests for biodiversity conservation have led to a totally different perspective as regards forest management: forestry of multiple objectives. The importance and effectiveness of the above services depend on forest composition and structure, conservation status and forest management, as well as on the social, economic, cultural and historical background of each area.

Recreation ground in Parnitha, Central Greece
EKBY Photo Archive/L. Logothetis

2.3.2. Production of wood and other products

One of the most important functions of a forest ecosystem is biomass production. A large percentage of this biomass, almost 50%, consists of wood. Wood is ecologically produced, as its production does not require the consumption of additional energy, i.e. it is a biologically renewable resource. Wood, either as a source of energy (firewood, charcoal) or as a construction material to be used in shipbuilding, furniture, decoration, paper production etc. has been used since ancient times and plays a significant role to the development and prosperity of human societies.

Wood extraction does not lead to forest destruction, provided that it is applied pursuant to the rules of forest science and sustainable management: *the extracted wood should not exceed the annual forest production and logging should serve the maintenance and improvement of forest composition and structure.* The wood obtained from forests corresponds to approximately 50% of the biomass harvested. The remaining 50% (branches, bark and roots) remains on the ground, contributing to the creation of humus that acts as a natural fertilizer.

Apart from wood, which is the main product of forests, forest ecosystems also offer a series of products with economic value, such as bark resin gum, honey, wild fruits (wild strawberries, blackberries, raspberries, cranberries, blueberries) as well as aromatic leaves (laurel), mushrooms, medicinal herbs, prey, forage material etc.

Wild strawberries
EKBY Photo Archive/A. Chantzaridou

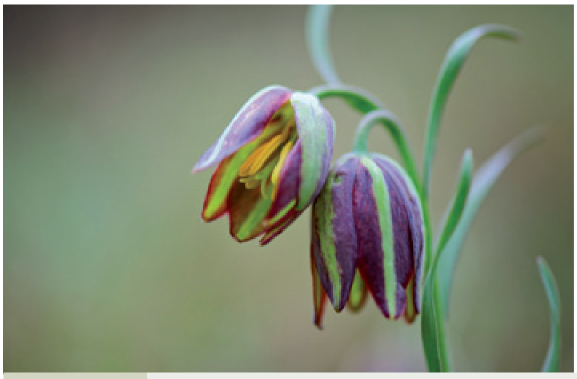
Sweet chestnuts
EKBY Photo Archive/A. Chantzaridou

Dogwood berries
EKBY Photo Archive/L. Logothetis

Logging on Rodopi mountain range, NE Greece
EKBY Photo Archive/L. Logothetis

2.3.3. Biodiversity conservation and protection

Forests are important repositories of terrestrial biodiversity, since they host a variety of plants and animals, interrelating with each other and with the abiotic environment: trees, shrubs, herbs, mosses, lichens, fungi, mammals, birds, amphibians, reptiles, worms, bacteria and protozoa form the forest ecosystem. The forest is not only a refuge providing habitat for plants and animals, which would have otherwise become extinct, but is also a valuable gene pool.



Fritillaria flower
EKBY Photo Archive/L. Logothetis

Rüppell's warbler
EKBY Photo Archive/L. Logothetis

EKBY Photo Archive/L. Logothetis

The waterfall of Lepidas in Rodopi, NE Greece
EKBY Photo Archive/L. Logothetis

2.3.4. Water regulation

The most important forest functions related to water regulation are the prevention of floods, the reduction of flood peaks and the enrichment of groundwater aquifers. The great water storage capacity of forest soil renders it a large regulatory tank, which retains water during precipitation period and releases it again during the dry season, maintaining a constant sources supply. The importance of the forest impact to flood prevention is very often evident in Greece; following the destruction of forests due to fires and if the necessary measures are not taken, devastating floods usually take place.

Forests maintain in their canopy (foliage) a more or less important part of precipitation water, which never reaches the ground but evaporates directly in the atmosphere. On average, the percentage of this water retention amounts to 10-20% for deciduous species and to 30-40% for evergreen conifers. In Greece, where the majority of forests consist of deciduous species (that do not bare leaves during the winter), this percentage is much smaller.

Finally, the influence of the forest to water quality is significant. The forest litter and forest soil act as a biological filter, so that the water "produced" in the forest is the best in every aspect: organoleptic, chemical and microbiological. In the future, it seems that the most important product of forests will be water, both in terms of quality and quantity.

2.3.5. Protection from soil erosion

Forests play a very important role both in soil formation and in soil protection. Erosion depends on the type of soil, its morphology (relief), its cover, as well as the intensity and duration of precipitation period. Forests protect the ground from alluvial and wind erosion and therefore from degradation and desertification. In Greece, as in all Mediterranean countries, the destruction of forests contributes significantly to soil erosion and desertification.

Black pine forest on Mount Parnonas, Peloponnese
EKBY Photo Archive/L. Logothetis

2.3.6. Windproof protection

Forests act as a barrier to the movement of wind and may change the speed, direction and structure of the wind both in the forest's interior and at the adjacent uncovered surface areas. The reduction of wind speed in the forest is due to: a) the fact that the wind mass that strikes to the forest's verges cannot entirely pass through and is consequently diverted and b) the resistance of tree stumps, branches and shrubs. Therefore, the wind speed is progressively reduced from the verges to the interior part of forests.

The forest impact on the wind speed is important not only to maintain a balanced climate within the forests, but also for crops growing near their leeward part. This applies largely through the creation of windproof fences to protect crops and soil from wind.

2.3.7. Impact on atmosphere composition - CO_2 absorption

As a production factor, CO_2 constitutes the foundation of life in our planet, as it is a necessary element for photosynthesis. It is also one of the gases responsible for the greenhouse effect and climate change.

The increase of atmosphere content in CO_2 would be much larger if the feedback mechanisms (regulatory mechanisms), mainly oceans and forests, have not been active. Forest vegetation and soil play an important role as carbon sinks, since they contain almost half of the carbon that can be found on land. Forests, through photosynthesis, absorb CO_2 and release it through respiration, degradation and forest fires. Unfortunately, forests are degraded by human activities; deforestation and forest degradation is considered to be responsible for about 17% of greenhouse gases' emissions worldwide[5].

2.3.8. Aesthetic and health benefits of forests

With the increasing urbanization, urban forests constitute natural oases, improving the physical and mental health and the overall life quality of people living in towns and cities. Nowadays, forests possess a particular value and importance as recreation areas for physical and mental uplift. The forest air is free from pollution and dust; it contains easily evaporating substances, such as essential oils and terpenes, which stimulate the human body.

In recent years, everywhere around the world and lately in Greece, forest tourism has been developed. It is mild, environmental-friendly form of tourism; the Greek Forest Services, despite the lack of personnel, means and finance, have worked hard to develop and construct paths and to create organized snack places and watching areas.

5. Intergovernmental Panel on Climate Change (IPCC). 2007. Climate change 2007: Synthesis report. Contribution of working groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. R.K. Pachauri and A. Reisinger, eds. Geneva, Switzerland.

Morning mist in Aspropotamos, South Pindos
EKBY Photo Archive/L. Logothetis

2.3.9. Forests as a landscape mark[6]

Forests constitute a dominant element of the landscape. Any alteration in forest composition and structure changes the landscape image. As forests change with seasons, they highlight the changes of landscapes. Consequently, when applying forest management practices (especially during reforestation activities, management of degraded forests and introduction of alien species to natural system) the conservation of the landscape profile must be seriously taken into account.

6. Landscape is the visual effect resulting from the combination of soil morphology and a mosaic of several natural and human ecosystems that can be found in a given area.

2.4. Threats to forests[7]

Forests in Greece, as in all Mediterranean areas, and in particular coastal forests and forests at low altitudes, are exposed for thousands of years to human activities (e.g. urbanization, conversion into agricultural land etc.) resulting in their degradation. The most important threats to Greek forests are:

- The gradual change of land cover (legal or illegal), land clearings and encroachment of human activities to wooded land and high forests (constructible land, primary sector pressures and infrastructure).
- The repeated within short time periods forest fires, the frequency and intensity of which is expected to further increase due to climate change, combined with the lack of protection to forest ecosystems.
- The application of non-environmental wood harvesting methods, such as the use of heavy machinery etc.
- The lack of sustainable management during several phases of forest production.
- The diseases caused by pathogens, such as chestnut ulcers, the Dutch disease that affects elms (*Ulmus campestris*), the cypress cancer, the Greek fir infestations by bark beetles, as well as palm infestation from the insect *Rhynchophorus ferrugineus*.
- Climate change (prevalence of drier conditions due to the increase of average temperature, occurrence of extreme weather events), as a result of which the current threats for forests are expected to further intensify and new ones to appear.

7. Ministry for the Environment, Energy and Climate Change. 2014. National Strategy and Action Plan for Biodiversity.

3 Forests and climate change

3.1. General information

Climate change is considered to be a consequence of all the previous and current human activities on Earth[8]. The global average temperature has risen by approximately 0.8°C compared to the pre-industrial period levels and is still increasing. In Europe, the rise in temperature was even greater than the global average (1.3 °C compared to pre-industrial levels)[9]. Europe is exposed to climate change, and some areas in particular, such as the Mediterranean basin, mountain areas, densely populated plains, coastal areas and the Arctic, seem to be highly vulnerable and more endangered than others[10]. Especially in the Mediterranean, the temperature seems to rise while the precipitation seems to be drastically reduced during winter and summer (data regarding the last half of the 20th century)[11].

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8. IPCC. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K. and A. Reisinger (eds.)]. IPCC, Geneva, Switzerland, 104p.
9. Report No.12/2012 of the European Environmental Bureau (EEB): Climate change, impacts and vulnerability in Europe 2012.
10. COM. 2013. ANNOUNCEMENT OF THE COMMISSION TOWARDS THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. Strategy of the European Union for adaptation to climate change.
11. Giannakopoulos, C., Bindi, M., Moriondo, M., LeSager, P. and T. Tin. 2005. Climate change impacts in the Mediterranean resulting from a 2ºC global temperature rise. Rapport préparé pour le WWF. Observatoire national d'Athènes, Grèce.

Mixed Black pine, beech and fir forest in Aspropotamos, South Pindos
EKBY Photo Archive/L. Logothetis

The main climate change characteristics, apart from the gradual temperature rise, are the following:

- Reduction of the duration of precipitations and increase of their intensity, prolongation of summer and prevalence of drier springs and irregular winters.
- More frequent and more intense occurrence of extreme weather events (dry seasons, heat waves, storms, hail-storms etc.).
- Increase of surface runoff and reduction of water storage capacity in the soil due to heavy precipitations (storms) within a short time period. As a result, floods and risk of soil erosion are increased.

Forests contain approximately 50% of the overall carbon stored in terrestrial ecosystems and strongly interact with climate, since they act as CO_2 sinks during their growth and as a CO_2 source in the atmosphere when destroyed by natural or anthropogenic causes (deforestation, degradation, inadequate or inappropriate management, forest fires etc.)[12]. Furthermore, the conservation of forest ecosystems is directly affected by climate parameters (temperature, precipitation etc.) as well as by the possible impact that these climate parameters' alterations might have on abiotic parameters (e.g. availability of water and nutrients), biotic parameters (inter-species competition), the intensity and frequency of disturbances (e.g. forest fires, pathogens' outbreaks, extreme weather events) etc.

Information and knowledge on the impacts of climate changes on forest ecosystems is essential for humans, as forests contribute to the prosperity and life quality. With the current applied management strategies and if no additional measures are taken, it is estimated that by 2100, there will be a spatial redistribution of forests in Greece, a reduction of forest canopy closure (specifically for Norway spruce, fir, beech and Black pine forests a 4%-8% decline is expected), a reduction of forest ecosystem carbon storage capacity (32% to 45% compared to today), a reduction in wood production (by 27-35%), as well as an increase of costs for the implementation of repressive firefighting measures due to the increase of forest fires[13].

12. FAO [Food and Agriculture Organization of the United Nations]. 2005. Global Forest Resource Assessment 2005: Progress Towards Sustainable Forest Management. FAO Forestry Paper 147. FAO, Rome.

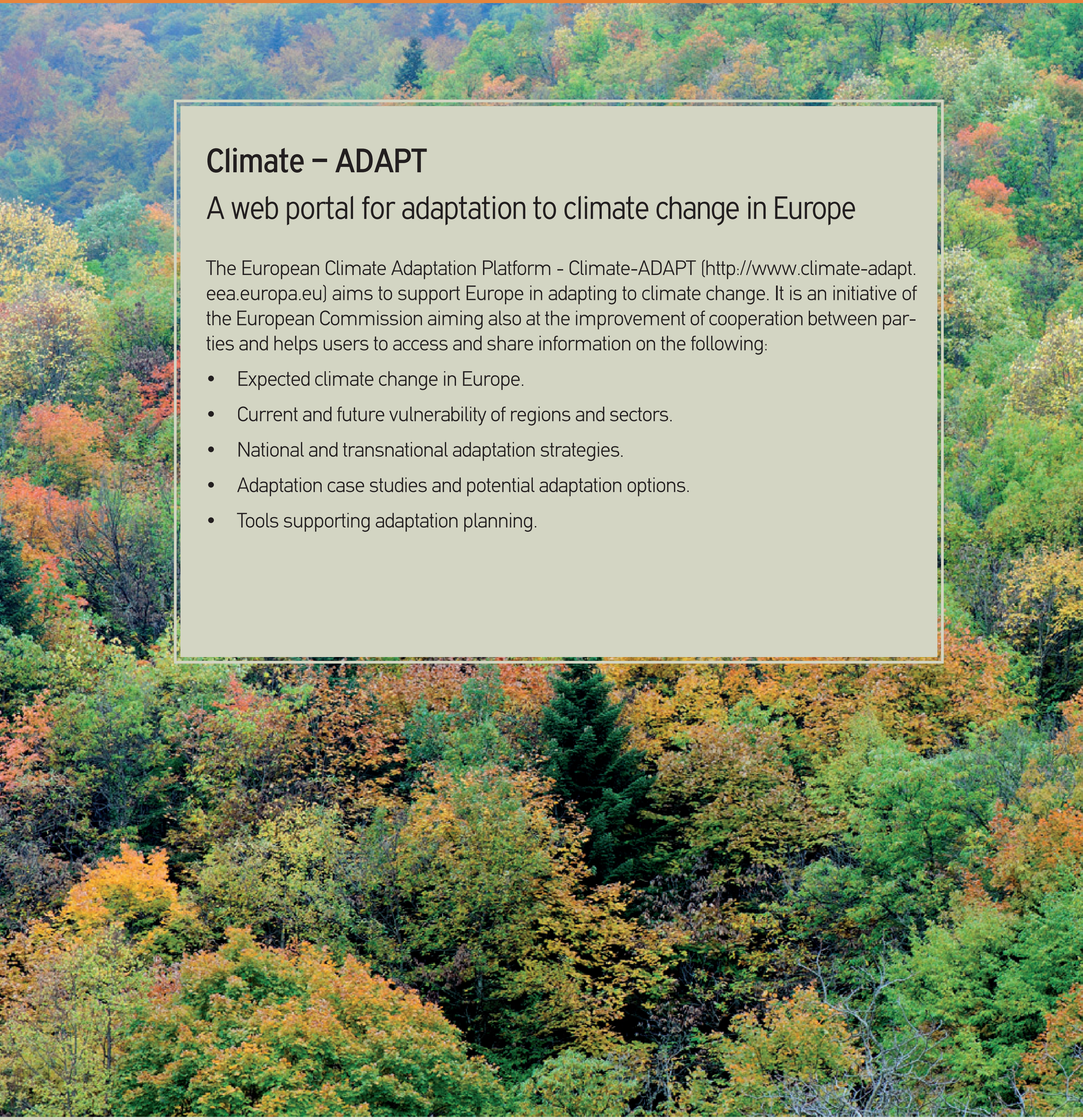
13. Nastis, A., Karmiris, H., Sartzetakis, E. and S. Nastis. 2011. Impact of climate change on forest ecosystems in the 21st century. In: the Environmental, economic and social consequences of climate change in Greece. The Bank of Greece.

Climate – ADAPT

A web portal for adaptation to climate change in Europe

The European Climate Adaptation Platform - Climate-ADAPT (http://www.climate-adapt.eea.europa.eu) aims to support Europe in adapting to climate change. It is an initiative of the European Commission aiming also at the improvement of cooperation between parties and helps users to access and share information on the following:

- Expected climate change in Europe.
- Current and future vulnerability of regions and sectors.
- National and transnational adaptation strategies.
- Adaptation case studies and potential adaptation options.
- Tools supporting adaptation planning.



Intrusion of Bulgarian fir and Black pine in Kastania Municipal Forest, South Pindos
EKBY Photo Archive/L. Logothetis

3.2. Impact of climate change on forests[14]

3.2.1. General information

Climate change impacts on forest ecosystems are expected to be diverse and affect, as mentioned above, the health and stability of forests. As a result, climate change is expected to negatively affect their functions and the services they provide to humans. For example, changes in the hydrological cycle (spatial and temporal changes of precipitation distribution patterns) are expected to limit the availability of water produced by forests and impair its quality, thus reducing the protective role of forests as regards soil erosion, floods, strong winds etc.

Climate change may have opposing effects on forests: on one hand, European forests face changes, which occur gradually, in a stepwise manner, such as the change or movement of forest species and ecosystems and changes in productivity. On the other hand, forests are likely to be even more exposed to extreme phenomena, such as forest fires, drought, and pathogens' outbreaks. Gradual changes and extreme weather events may either act cumulatively or counterbalance and counteract each other's action when impacting on forests. For example, in North Europe, the observed increase in productivity can be offset by the increase in the frequency and intensity of phenomena such as storms and insects' outbreaks. In South Europe, however, the impacts of climate change seem to act cumulatively, as the gradual reduction of productivity combined with the increase of extreme phenomena such as drought and forest fires seem to result in increased tree mortality, or even in the replacement of forests by new vegetation types[15].

The Mediterranean forest ecosystems are expected to suffer to a greater extent from changes in climate parameters, compared to forest ecosystems in other areas, since the Mediterranean is considered to be a climate change hotspot[16]. Moreover, in South Europe, abiotic conditions result in low productivity of forests, due to a combination of limiting factors such as low soil fertility, steep slopes and risk of soil erosion. However, in the Mediterranean, the social and environmental services provided by forest ecosystems to humans, such as the conservation of biodiversity, the protection from floods, the landscape diversity and recreation are deemed to be much more important than those of North Europe's forest ecosystems[17].

In the following chapters, the impacts of climate change on forest ecosystems are presented, and emphasis is given on the Mediterranean forest ecosystems.

14. *Adaptation from:* FAO. 2013. Climate change guidelines for forest managers. FAO Forestry Paper No. 172. Rome, Food and Agriculture Organization of the United Nations.

15. Lindner, M., J.B. Fitzgerald, N.E. Zimmermann, C. Reyer, S. Delzon, E. van der Maaten, M-J. Schelhaas, P. Lasch, J. Eggers, M. van der Maaten-Theunissen, F. Suckow, A. Psomas, B. Poulter and M. Hanewinkel. 2014. Climate Change and European Forests: What do we know, what are the uncertainties, and what are the implications for forest management? *Journal of Environmental Management* 146: 69-83.

16. Giorgi, F. 2006. Climate change hot-spots. *Geophys. Res. Lett.,* 33(8): L08707, doi: 10.1029/2006GL025734.W.L.

17. Lindner, M., M. Maroschek, S. Netherer, A. Kremer, A. Barbati, J. Garcia-Gonzalo, R. Seidl, S. Delzon, P. Corona, M. Kolström, M.J. Lexer and M. Marchetti. 2010. Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. *For. Ecol. Manag.,* 259: 698-709.

3.2.2. Forest productivity

Climate change is expected to affect forest productivity either in a positive or in a negative way. On one hand, the increase of CO_2 in the atmosphere is expected to affect tree growth and consequently result in an increase in primary production, mainly in Northern countries. On the other hand, drought combined with an increase in the intensity and frequency of disturbances (e.g. forest fires, pathogens' outbreaks) are expected to cause further stress to trees or even their necrosis, leading to a reduction in forest productivity, in the Mediterranean countries[11]. The positive impact of climate change (e.g. rise in productivity) will most probably have a temporary effect as in the end it will be counterbalanced by the indirect negative impacts of climate change (e.g. reduction in precipitation or changes in its distribution patterns, increase of disturbances etc.). The expected reduction in forest ecosystem productivity will probably affect local communities depending on forests for their survival.

3.2.3. Biodiversity

The biodiversity of forest ecosystems is expected to be directly or indirectly affected, as certain species are expected to become extinct (e.g. due to the loss of their habitats), some species will be replaced by others, more resistant to the new adverse conditions or more competitive. Even the loss of individual species may have serious impacts on the stability of forest ecosystems. Specifically in Europe, it is estimated that approximately one third of the plant species is expected to disappear from its current location by 2050[18].

Furthermore, climate change is expected to have various impacts and cause changes both in the distribution of forest species and the composition and structure of forest ecosystems. In general, the shifting of forest ecosystems to a higher latitude and altitude is expected. In the Mediterranean, it is believed that the new climate conditions will favor dry-tolerant species and, as a result, their distribution is expected to increase. In Greece, a country notable for its great species diversity and intra-species genetic diversity, no evident change in the composition of forests has been observed so far, as for example in South Portugal. However, in Northern Greece, and specifically in the sub-continental zone of deciduous oak forests, an invasion of mountainous Mediterranean conifers has been observed (Black pine, Bulgarian fir) which may be attributed to climate change.

18. Bakkenes, M., Alkemade, J.R.M., Ihle, F., Leemans, R. and J.B. Latour. 2002. Assessing effects of forecasted climate change on the diversity and distribution of European higher plants for 2050. *Glob Change Biol* 8 (4): 390–407.

Extended forests on mountainous Peloponnese
EKBY Photo Archive/L. Logothetis

Populations of species that occur within the limits of their geographical distribution are considered to be vulnerable to both climate and environmental parameters' changes, as they usually occupy less favorable habitats. The loss of such marginal populations is deemed to be a serious problem for biodiversity, as these populations usually exhibit greater genetic diversity than the populations in the center of the species distribution[19,20]. Consequently, the loss of these populations will result in the reduction of the genetic diversity of the respective species[21,22].

3.2.4. Water resources

Climate change is expected to result in a) alterations in the spatial and temporal precipitation distribution patterns, b) an increase of surface runoff[23], c) changes in species physiology (e.g. increase of evapotranspiration) and d) changes in structure (e.g. reduction of canopy closure) of forest ecosystems. As a result, a reduction of water availability is expected, both from a qualitative and a quantitative point of view.

19. Petit, R.J., Aguinagalde, I., de Beaulieu, J.L., Bittkau, C., Brewer, S., Cheddadi, R. et al. 2003. Glacial refugia: hotspots but not melting pots of genetic diversity. *Science* 300: 1563–1565.

20. Hewitt, G.M. 2004. Genetic consequences of climatic changes in the Quaternary. *Phil. Trans. R. Soc. Lond.* B 359: 183–195.

21. Vucetich, J.A. and T.A. Waite. 2003. Spatial patterns of demography and genetic processes across the species_ range: null hypotheses for landscape conservation genetics. *Conserv. Gen.* 4: 639–645.

22. Hampe, A. and R.J. Petit. 2005. Conserving biodiversity under climate change: the rear edge matters. *Ecol. Lett.* 8: 461–467.

23. The increase in surface runoff is associated with degradation of soil quality and, in extreme cases, with desertification.

Apart from the above mentioned direct impacts on the hydrological cycle, climate change is expected to cause degradation of the protective role of forests (as regards soil erosion, floods, strong winds etc.) as well as to affect the frequency and intensity of floods and other extreme events.

3.2.5. Forest fires

As a result of climate change, a dramatic increase of forest fire risk is expected due to the new meteorological conditions (rise in temperature and prolonged drought during summer, storms, lighting etc.) but mainly due to the prolongation of the favorable for fire time period.

It is generally understood that the frequency, severity and extent of forest fires will be increased in the Mediterranean. Furthermore, in economic terms, the cost of firefight, and the cost of restoration are expected to increase. In addition, forest fires are a significant source of greenhouse gases, further extending the phenomenon of climate change.

Finally, the impact of fires on the composition of vegetation is significant[24], especially when it comes to ecosystems that were not previously at risk and therefore they are not resistant or adapted to their occurrence.

3.2.6. Pathogens

As a response to climate change, a further increase of infestations from pathogens (fungi, insects etc.) is expected[25]. Climate change may favor pathogens in two ways: a) directly, by affecting the growth, survival, reproduction and distribution of pathogens and b) indirectly, by increasing the vulnerability of trees (i.e. by weakening the defense mechanisms of the host) and disturbing the equilibrium of interrelationships, e.g. by changing the relevant abundance of predators of such pathogens.

Pathogens and the diseases they cause may be early indicators of climate change at local level. As an example, some species, e.g. the bark beetle *Ips typographus,* have already acquired the ability to increase the number of generations per year as a response to the rise in temperature[26].

In Greece, during the last decades, an increase in tree necrosis has been recorded due to infestation from fungi and bark beetles. However, such infestations are usually a secondary phenomenon caused due to the weakening of trees from extensive droughts (water intake from the soil becomes difficult, as droughts, often accompanied by high soil temperatures, destroy the biologically active root system which is close to the soil).

24. Flannigan, M.D., Stocks, B.J. and B.M. Wotton. 2000. Climate change and forest fires. *Sci. Total Environ.* 262: 221-229.

25. Logan, J.A., Regniere, J. and J.A. Powell. 2003. Assessing the impact of global warming on forest pest dynamics. *Front Ecol Environ* 1(3): 130-137.

26. Faccoli, M. 2009. Effect of weather on *Ips typographus* (Coleoptera, Curculionidae) phenology, voltinism and associated spruce mortality in the southeastern Alps. *Environ Entomol* 38(2): 307-316.

4 Adaptation of forest management to climate change

4.1. Introduction

Greece is expected to be among the most vulnerable countries to climate change in Europe[27]. Therefore, and since the impact of climate change becomes more and more evident, it is necessary to design and implement appropriate adaptation measures for forest management[28] at all levels, from local to regional and national.

Forest ecosystems in most places around the world will eventually adapt autonomously (without human intervention) to climate change, however there may be losses. Thus, the importance of forests to society allows humans to affect the direction and timing of this adaptation[29]. The objective is the conservation of healthy, productive forests, which are capable to store more carbon and offer goods and services to humans.

27. CEC (Commission of the European Communities). 2007. Adapting to Climate Change in Europe - Options for EU Action. Green Paper. Brussels: EC.
28. In any case, **sustainable forest management** is the key pillar to the conservation of forest ecosystems, the reduction of their vulnerability against climate change and the enhancement of their adaptation.
29. Spittlehouse, D.L. and R.B. Stewart. 2003. Adaptation to climate change in forest management. *JEM* 4(1): 1–11.

Morning mist on Mount Pieria, NC Greece
EKBY Photo Archive/L. Logothetis

Adaptation and mitigation in forest management[30]

The adaptation to and mitigation of climate change are actually the two sides of the same coin: mitigation actions address the human causes of climate change and adaptation actions deal with the consequences.

Mitigation actions of climate change include measures for the stabilization or reduction of greenhouse gases' concentration in the atmosphere. This may be achieved either by reducing human greenhouse gas emissions or by increasing their removal rate from the atmosphere.

Adaptation actions to climate change refer to adjustments and regulation of natural or anthropogenic systems in response to the current or expected climate change impacts, in order to minimize the risks and vulnerability of these systems, and at the same time, to take advantage of the opportunities provided. Specifically in the forest sector, adaptation includes interventions and changes in management practices aiming at the reduction of the vulnerability of forests and societies near forest areas to climate change.

Measures for climate change mitigation are considered necessary for the reduction of human interventions on climate; however the impact of those measures on the average global temperature (worldwide) will be evident only in the following decades. For this reason, from now on and for many years in the future, adaptation measures should be implemented in order to reduce vulnerability of forest ecosystems and to ensure the continuous provision of forest products and services to humans. Besides, the cost of early action for adaptation is, in any case, less than the price of lack of adaptation.

The assessment of climate change impacts on forests is difficult due to the limited information and data regarding: a) alterations of climate parameters both in time and in space, particularly at local level and b) the vulnerability of forest ecosystems and species. Furthermore, the adaptation of forest management to climate change needs to take into account not only ecological, but also socio-economic considerations. In addition, the implementation of decisions regarding adaptation of forest management, such as the change of silvicultural forms or the change of growing stock composition per forest species, is a time-consuming procedure. In fact, forest management planning will have to rely on one or more climate scenarios, in contrast to the relevant stability of climate data on which it has been based until now. This considerable change imposes the adoption of more flexible planning techniques and tools. Through the use of a more focused monitoring program, the developments are assessed and potential adjustments are applied the soonest possible. This approach is called adaptive management.

30. FAO. 2013. Climate change guidelines for forest managers. FAO Forestry Paper No. 172. Rome, Food and Agriculture Organization of the United Nations.

The adaptation of forest management to climate change is actually such a process and its implementation includes the three following steps:

a) **Vulnerability assessment of forest ecosystems** to climate change.

b) Determination of management objectives for forests in the light of climate change and **development of cost-effective adaptation measures.**

c) **Monitoring** for assessing forest status as well as for evaluating the degree of success of the adaptation measures implemented and re-assessment of management objectives, actions and measures.

Furthermore, training of all stakeholders involved in forest management and public awareness regarding problems that may occur in the forest community due to climate change are required[31].

In the following chapters (4.2., 4.3. and 4.4.) a description of the three steps is provided, along with an example (case study) from the four study areas of the LIFE+ AdaptFor Project.

Detecting climate change in Parnitha, Central Greece
EKBY Photo Archive/L. Logothetis

Adaptive management

Adaptive management is indicated in complex situations with high degree of uncertainty, such as climate change. It is a dynamic approach, during which the changing conditions are constantly monitored and the applied practices are adjusted accordingly. Adaptive management combines planning, implementation, monitoring and subsequent review of management practices (if and when required).

31. Spittlehouse, D.L. and R.B. Stewart. 2003. Adaptation to climate change in forest management. *JEM* 4(1): 1-11.

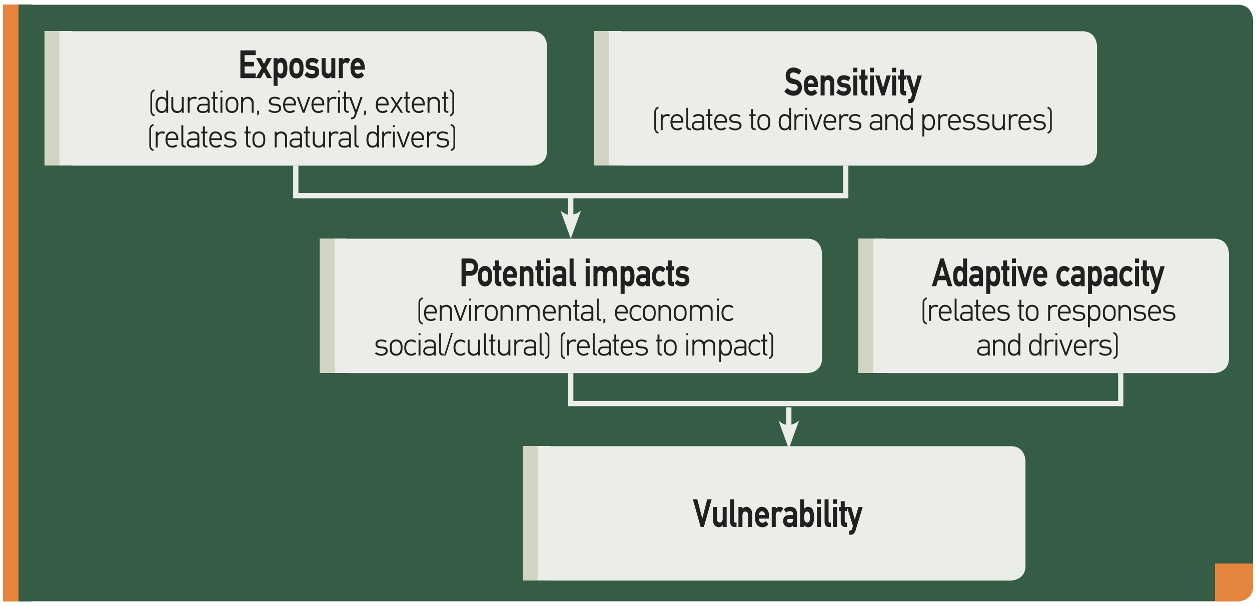
4.2. Assessment of forest vulnerability to climate change

The knowledge regarding vulnerability of forest ecosystems to climate change is important in order to design appropriate adaptation practices, not only as regards natural but also socio-economic systems and infrastructure. The vulnerability assessment of forest ecosystems is considered as the necessary first step in the process of forest management adaptation, as it provides significant information on the forest, even if the predictions for climate change and its impacts are considered highly uncertain. Besides, adaptation measures that are taken imprudently, without prior understanding of the impact that these measures might have on the ecosystems implemented, may have the opposite effects and may even deteriorate the status of forest ecosystems[32].

Vulnerability: *The propensity or predisposition of a system to be adversely affected by climate change. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt*[33].

Vulnerability is a combination of: the nature, magnitude and rate of climate change to which a system is exposed, the system's sensitivity against exposure to climate parameters and other pressures, the possible impacts on the system and the adaptive capacity of the competent authorities. The first step during the vulnerability assessment is to identify forest ecosystems and social groups (e.g. loggers, forest-dependent communities) that show greater vulnerability to climate change.

The framework for vulnerability assessment to climate change is presented in the following figure[34]:



32. Duinker, P.N. 1990. Climate change and forest management, policy and land use. *Land Use Policy* 7: 124-137.
33. Intergovernmental Panel on Climate Change. 2014. 5th. Assessment Report. Impacts, Adaptation and Vulnerability.
34. Intergovernmental Panel on Climate Change 2001, 3rd Assessment Report. Synthesis Report, Füssel and Klein 2006; Metzger *et al.* 2006.

Based on the above figure, the factors that determine forest ecosystem vulnerability to climate change may be summarized as follows:

Exposure	It regards exposition to climate parameters' changes, at the distribution area of the forest ecosystem in question, compared to the past, i.e. if there are considerable changes in the climate patterns (duration, intensity, degree) in each study area such as reduction of precipitation, increase in the frequency of extreme weather events, increase of average temperature or time period during which the maximum values are observed.
Sensitivity	It regards the degree of susceptibility of a forest species or an ecosystem to climate parameters' changes, in combination with other pressures, such as changes in land uses, inappropriate management practices etc. Populations located in the limits of the species distribution (such as Black pine in the Peloponnese or birch on Mount Rodopi) may be considered as susceptible to relatively small changes in climate conditions. However, due to the fact that these populations have managed to persist in adverse environments, it is possible that they have developed adaptation mechanisms and thus it is likely to better cope with the new, expected conditions, compared to the populations located in the center of the species distribution.
Potential impacts	It is the combination of the above two parameters as regards environmental impact. In addition, there are social and economical parameters, e.g. the possible reduction of wood extraction from a forest which may cause wider social and economic impact on local societies and loggers who depend on forest ecosystems.
Adaptive capacity	Adaptive capacity regards the ability of the competent services to plan and take the appropriate actions for forest management adaptation. Depending on the case, it may include parameters such as adequate infrastructure, procedures and methods, personnel's knowledge and skills and in general the level of awareness of forest populations, loggers and local societies on the subject.

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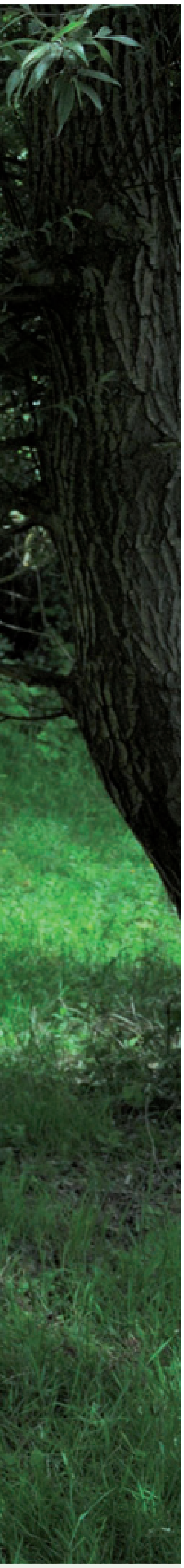


Knowledge as a tool

The assessment of vulnerability may be performed through numerous approaches, using different methods and sources of information, such as local information, expert opinion, collection of detailed data and statistical analysis.

Forest Services should consider existing available information and data from research institutes, monitoring programs or other sources, including meteorological data from local stations. Data and information deriving from field observations and inventories, other monitoring programs, as well as information coming from local residents are always useful. In certain cases, the research for the investigation of phenomena that may be attributed to climate change should be focused (e.g. infection from fungi or insects).

The vulnerability assessment may be qualitative or quantitative and the scale of the assessment may depend on the available information and financial resources, the available time, the size of the area, the problem to be addressed, the kind of decisions that this assessment will support and finally the value and importance of the endangered natural resources.

LIFE+ AdaptFor:
STEP 1- Vulnerability assessment

The first step in the process of adapting forest management is the assessment of vulnerability of forest ecosystems to climate change. At the four study areas of the Project LIFE+ AdaptFor, the vulnerability assessment has been carried out through a) field work, b) remote sensing techniques, c) data collection from the archives of the local Forest Services and d) literature review. It included the assessment of forest ecosystem vulnerability in terms of:

- **Forest health** (pathogens such as fungi and insects): establishment of pheromone traps, detection and identification of pathogen fungi and harmful insects, mainly bark beetles, assessment of the degree of infections and insect biodiversity assessment (Shannon-Weiner H' Index).

- **Changes in forest vegetation:** selection of suitable for analysis satellite images (based on the minimum cloud and snow coverage) with the greatest time distance, production of digital elevation models (DEMs), satellite image analysis (photo-interpretation), application of supervised classification and changes identification techniques, accuracy assessment on the above classifications.

- **Phytosociology:** assessment of the differentiation of vegetation (classification of different vegetation units depending on site quality, plant community succession stages, altitude differentiation etc.), calculation of Ellenberg Indicator values (for the following ecological factors: soil acidity and humidity, soil nutrients, temperature, degree of continetality and lighting conditions, classification of plant taxa in chorological units (e.g. Balkan, Greek endemic, Mediterranean mountain, stenomediterranean etc.), classification of biotic forms (chamaephytes, geophytes, hemicryptophytes, phanerophytes and therophytes), assessment of change in ecological factors (compared to previous sampling data).

- **Ecophysiology:** inventory of tree biometrics (measurements on live and dead standing and decumbent trees), inventory of shrubs and regeneration, assessment of vitality or decomposition degree, dendrochronology.

- **Soil:** soil description (e.g. rock type and parent material, slope, exposition, horizon thickness and content in skeletal material, erosion conditions, litter condition etc.), analysis of soil nutrients and plant tissues (e.g. leaves, stems etc.), calculation of the available water for plant growth.

At the same time, time series of temperature and precipitation for the period 1950-2009 have been produced for each of the four study areas. The purpose was to investigate possible correlation of the observed phenomena in the above areas with changes in meteorological parameters, as well as to study the evolution of these phenomena within a relatively long time period, under the effects of climate change. Both time series (temperature and precipitation) supported the hypothesis of climate alterations during the last decades. In particular, as regards temperature, the time series has shown an increasing trend in all areas except Aspropotamos-Kalampaka forest, while the precipitation time series has shown a decline in all four study areas.

The results of forest's assessment have been combined with the climate data, as derived from the time series analysis, in order to define vulnerability of each forest ecosystem to climate change. In the following table, a brief description of the four areas (in terms of vegetation) and the results of the vulnerability assessment are provided.

Extraction of core samples from Greek fir for tree ring dating at the National Park of Parnitha, Central Greece
EKBY Photo Archive/L. Logothetis

Ritini-Vria Forest at Mount Pieria

Vegetation type	Scots pine (*Pinus sylvestris*) in pure stands with an understory of low shrubs
Vulnerability assessment	The extensive dieback of Scots pine in this area over the last 30 years seems to be the result of the combined action of the primary pathogenic fungus *Peridermium pini* and of bark beetles, mainly *Ips acuminatus* (complex disease). The available evidence supports the original hypothesis that changes in climate parameters over the years have considerably contributed (temperature increase favors the insects; humidity increase favors the fungus; drought weakens the tree defense mechanisms).

Scots pine dieback on Mount Pieria
EKBY Photo Archive/L. Logothetis

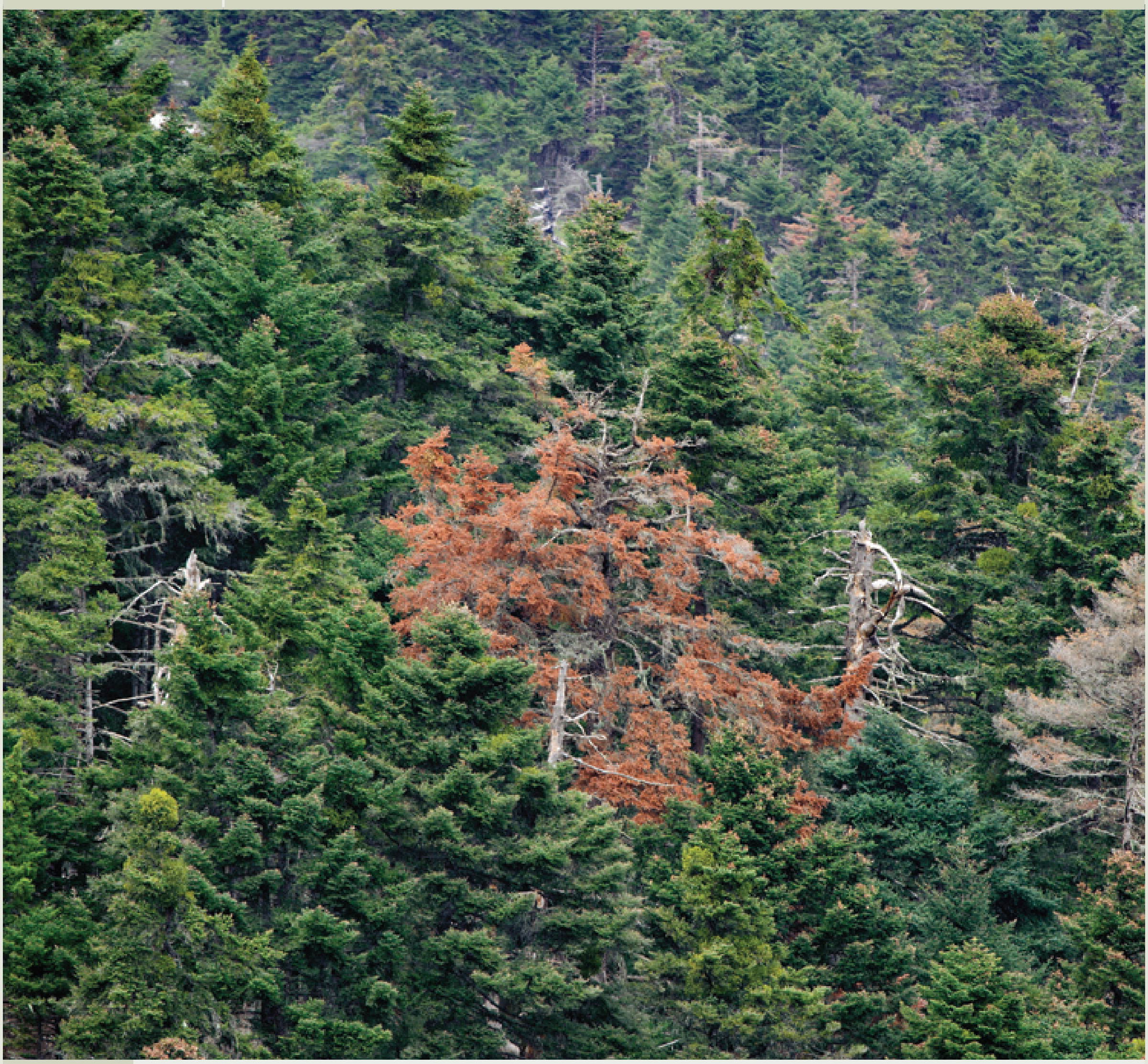
Aspropotamos-Kalampaka Forest

Vegetation type	Mixed stands of deciduous broadleaved species, such as Turkey oak (*Quercus cerris*), Hungarian oak (*Quercus frainetto*), Downy oak (*Quercus pubescens*), Chestnut (*Castanea sativa*), Bulgarian fir (*Abies borisii regis*) and Black pine (*P. nigra*)
Vulnerability assessment	Over the last decades, coniferous species, especially Bulgarian fir, have intruded into lower surface areas where broadleaved forests prevail (700-1000 m). As a consequence, fir extends beyond its lower thermal tolerance limits, becoming vulnerable to insects' outbreaks. It was assumed that the management and silvicultural practices applied in the area for many years (coppicing, clear cuts) might have led to the weakening of the broadleaved forest, reducing its competitiveness and thus rendering broadleaved species less competitive against conifers which tend to occupy the available ecological niche.

Intrusion of Bulgarian fir in oak forest in Kastania, Kalampaka, South Pindos
EKBY Photo Archive/L. Logothetis

National Park of Parnitha

Vegetation type	Greek fir (*Abies cephalonica*) in pure or mixed stands with Aleppo pine (*Pinus halepensis*), juniper (*Juniperus* sp.), Kermes oak (*Quercus coccifera*) and broadleaved shrubs
Vulnerability assessment	The dieback of Greek fir, observed for many decades, resulted from the outbreak of bark beetles (mainly *Pityokteines spinidens*, which is highly influenced by changes in climate parameters). The low levels of insect diversity indicate a rather sensitive and unstable ecosystem. Moreover, the huge amount of decaying wood that remained in the forest after the 2007 fire, in combination with the adverse soil and climate conditions, have favored the expansion of harmful bark beetles.

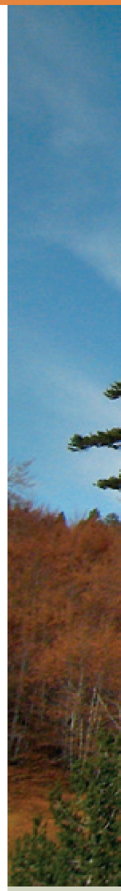


Greek fir dieback at the National Park of Parnitha, Central Greece
EKBY Photo Archive/L. Logothetis

Mount Taygetos

Vegetation type	Greek fir (*A. cephalonica*) in pure or mixed stands with Black pine (*Pinus nigra*), juniper (*Juniperus* sp.) and broadleaved shrubs
Vulnerability assessment	Greek fir has suffered several insect infestations by bark beetles (mainly *P. spinidens* and *Hylastes brunneus*). However, high levels of occurrence of the beneficial predator insect *Thanasimus formicarius* together with high levels of insect diversity indicate a rather stable ecosystem that can resist a possible population expansion of insects.

Greek fir dieback on Mount East Taygetos, Peloponnese
EKBY Photo Archive/L. Logothetis



4.3. Adaptation measures

4.3.1. General principles and framework

Following the vulnerability assessment of the forest ecosystems (see above), the next step is to lay down the appropriate measures in order to adapt forest management to climate change.

Almost all Greek forests are natural, and even for forests created through afforestation, species of local origin have been used (with few exceptions). Furthermore, Greek forests exhibit great species diversity but also a strong genetic variability within species. However, with the exception of coniferous forests and around one fifth of deciduous broadleaved forests, Greek forests are degraded mainly due to coppice management (low forests) or even due to non-management (as in the case of most evergreen or deciduous broadleaved shrubs). Therefore, the rehabilitation and restoration potential for Greek forest ecosystems, aiming at their adaptation to climate change as well as at the improvement and maximization of provided services for local communities, is quite strong.

Although, as mentioned above, the future climate conditions can not be projected with accuracy yet, the timely development and adoption of adaptation strategies is considered necessary, long before the impacts of climate change to forests become evident[35]. Besides, adaptation actions and measures of a preventive nature are always preferable than remedy ones. To adapt forest management to climate change, the measures need to: a) address management problems in a holistic way and no longer according to the traditional perception by which forest management is implemented only for wood-productive purposes, b) meet, in scientific terms, with the management needs of the forest ecosystems and c) take into account applicability issues, in terms of cost and social acceptance, the local social conditions etc.

Subsequently and in accordance with the above, the adaptation framework to tackle the impacts of climate change to Greek forests is provided below.

35. Spittlehouse, D.L. and R.B. Stewart. 2003. Adaptation to climate change in forest management. *JEM* 4(1): 1–11.

Beech forest with Bosnian pines in Valia Kalda, Pindos mountain range
EKBY Photo Archive/L. Logothetis

Framework of adaptation actions and measures of forest management to climate change in Greece

- Conserve plant and animal species' habitats and protect of biodiversity at all levels (genetic diversity, diversity of species, ecosystems and landscapes).
- Favor the prevalence (or selection through planting) of forest plant species, varieties and genotypes that are better adapted to drought and more resistant to extreme weather events and other disturbances (e.g. forest fires, pathogens' outbreaks etc.).
- Adapt management and silvicultural forms to the demands arising from climate change, i.e. creation of high forests, uneven-aged (selective or group selective silvicultural systems) and mostly mixed forests, where appropriate.
- Adapt silvicultural and harvesting practices to a drier climate, with increased possibilities of extreme weather events and other disturbances. Such forest practices may include reduction of stand density, especially in the phases of thin and thick adolescent and thin poles through high thinning, in order to reduce competition, protect soil organic matter (protection from erosion) etc.
- Adopt management measures to address the increased forest fire risk, especially in the Mediterranean zone, and invest in means and measures of prevention, early detection and suppression (rapid response).

In chapter 4.3.2., the above framework is further specified in proposed adaptation actions and measures to tackle the effects of climate change regarding forest productivity, biodiversity, water and soil resources, forest fires, pathogens' outbreaks and extreme weather events. Moreover, specific adaptation measures are proposed for the main Greek forest ecosystems, categorized per vegetation zone (chapter 4.3.3.). Finally, in chapter 4.3.4., horizontal measures (general socio-economic and administrative measures) are described.

It is noted that the adaptation measures included in the present guidelines:

- Are no or low regret measures[36]: Given the many uncertainties regarding future climate conditions, especially at local level, measures corresponding to a wide range of possible climate changes or that are considered to be beneficial for forest ecosystems even if no phenomena attributed to climate change eventually occur (e.g. no forest fires or pathogen outbreaks) are selected.
- Ensure synergies with other policies: Measures which, at the same time, serve purposes of adaptation to climate change, biodiversity conservation and climate change mitigation, are proposed.
- Are soft: Measures which promote the protection, enhancement or restoration of forest ecosystems' natural processes are preferred. At the same time, measures including constructions or works that may have negative impacts on forests are avoided. Many of the proposed measures are in fact based on existing "good forest management practices", however to combat the effects of climate change, these measures are organized and combined in a totally new context.
- Address pressures and threats: Measures which address pressures and threats often exerted on forest ecosystems are selected, in order to reduce their overall sensitivity.
- Enhance the adaptive capacity of Forest Services: An essential component of proper planning and subsequent implementation of adaptation measures is the enhancement of Forest Services' personnel in means, skills and knowledge, through training and exchange of "good practices".
- Enhance the services that forest ecosystems provide to humans: This mainly regards measures that ensure protection of local communities from floods, soil erosion etc. They also promote the use of forests for the protection of both resources and communities from the effects of climate change (nature-based approaches).

The proposed measures are based on the precautionary principle: *"Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation"* (Rio Declaration, 1992).

36. Fussel, H.M. 2007. Adaptation planning for climate change: concepts, assessment approaches, and key lessons. *Sustain. Sci.* DOI 10.1007/s11625-007-0032-y.

4.3.2. Adaptation measures for the enhancement of the main functions of Greek forest ecosystems

4.3.2.1. Forest productivity

The total forest area (forests and other forested land) in Greece amounts to approximately half of the country's total surface area. This area includes: a) productive forests, mainly of coniferous but also of deciduous broadleaved species, largely managed as coppice and b) deciduous and evergreen broadleaved shrublands, which in most cases are degraded forms of forests. Therefore, one of the main objectives of forest management in Greece is to maintain the productivity of Greek forests. In the framework of forest management adaptation under the effects of climate change, Forest Management Plans should take into account possible alterations in forest productivity as measured through annual increment. Adaptation measures aiming at the conservation of forest productivity and, where feasible, its enhancement, include:

- Selection (during plantation) or favoring (through enhancement and protection of natural regeneration) of species and varieties adapted to current and expected climate conditions (e.g. thermophilic and drought-tolerant species).
- Management of the understory vegetation and of the middle level floor, aiming to reduce competition for soil humidity (and thus reduce water stress caused due to increased drought) and to favor the main commercial tree species.
- Modification of sylvicultural treatments (e.g. thinning, pruning etc.) and final logging activities (e.g. rotation period etc.) in order to improve the quality of logged wood (e.g. timber larger in size).
- Implementation of supplementary protective measures (e.g. regulation of grazing, protection of soil resources during the implementation of silvicultural treatments etc.) in order to maintain soil structure and productivity.
- Development of economic activities for forest-depended communities through promoting a) the disposal of affected, degraded wood products for other uses (e.g. pulp, firewood, poles etc.) and b) the exploitation of new forest products (e.g. pellets).

Logging in Rodopi, NE Greece
EKBY Photo Archive/L. Logothetis

4.3.2.2. Biodiversity

Biodiversity conservation is an essential parameter for the success of forest ecosystem management against climate change. Consequently, forest management should be adapted in favor of biodiversity, which actually constitutes the foundation for the enhancement of services that forest ecosystems provide to humans. Forest adaptation management measures should aim to protect biodiversity and at the same time to increase the resilience of forests to climate change. These measures may include:

- Establishment of new or expansion of existing protected areas for the conservation of vulnerable forest ecosystems and species.
- Control of threats and pressures to forest ecosystems that are considered to be vulnerable to climate change (e.g. through regulation of grazing, cessation of unsustainable management practices or changes in land use etc.).
- Favoring and preservation of plant species, varieties or genotypes adapted to the current or future climate conditions (e.g. thermophilic and drought-tolerant species or forest species populations at their distribution limits, as the latter are already better adapted to extreme conditions compared to the populations at the centre of the species distribution).
- Enhancement of the diversity at species composition level (mixed stands), age classes (uneven-aged forest stands) and functional plant groups (e.g. broadleaved-conifers forests).
- Reduction of the annual harvest and extension of the rotation period for forest species, whose distribution or vitality (physiology, phenology) may be affected by climate change.
- Implementation of measures for the early detection, immediate extermination and long-term control of invasive alien species.
- Creation, preservation or restoration of ecological corridors, in order to facilitate the movement of species due to climate change and to increase the functional connectivity of forest ecosystems.
- Monitoring of forest ecosystems and species to assess the impacts of climate change on biodiversity and also to measure the success resulting from the implementation of all the above measures.

Beech forest in Chaidou, Rodopi, NE Greece
EKBY Photo Archive/L. Logothetis

4.3.2.3. Water and soil resources

The expected impacts on water and soil resources due to climate change are coarsely divided into two categories: a) extension of drought period, possibly resulting in tree water stress and b) alterations in seasonal distribution patterns of precipitation. In the second case, it is imperative to protect natural resources, as well as the local societies from floods and soil erosion. In this context, the improvement of early warning and communication systems between all parties involved at local level is considered to be a priority. Forest management adaptation measures, in order to address the above impacts, include:

- Favoring or selection of drought-tolerant species which at the same time can use water in an efficient way.
- Maintenance and elevation of treeline aiming to reduce surface runoff and to increase infiltration and water storage capacity of soil (enrichment of aquifers).
- Cessation of clear cuts in vulnerable areas and adaptation of management and silvicultural forms in other areas, aiming to increase water storage capacity of soil and to reduce soil erosion and siltation.
- Preservation or increase of forest vegetation cover in upstream areas which are prone to erosion and floods.
- Construction of water and erosion control infrastructure in mountainous areas to reduce flood risk downstream and increase inflow to aquifers.

4.3.2.4. Forests fires

In the context of climate change, forest management should incorporate measures to prevent and tackle the risk of forest fires at local and regional level. Specifically, management plans should incorporate actions and measures for the prevention, early detection and immediate intervention, management and suppression of fires. In fire-prone forests, the identification and mapping of the most vulnerable forest stands is very important, so that priority at their protection against fires is given. It should be noted that in the Mediterranean zone, forest fires always occurred and will continue to occur in the future. Mediterranean ecosystems are well adapted to this form of disturbance and can easily regenerate following a fire incident. Therefore, post-fire management must constitute an integral part of management plans. The first concern should not be reforestation (which -if inappropriately applied- may cause greater damage than the fire itself) but the immediate implementation of measures against soil erosion (as the soil has lost its protective cover due to the fire) and flood phenomena. The actions and measures proposed to this direction include:

Prevention measures

- Assessment of fire risk during forest management planning (e.g. estimation of the quantity of potential fuel during monitoring activities).
- Implementation of appropriate silvicultural treatments (e.g. thinning, pruning, removal of the flammable understory to prevent the conversion of ground to crown fires, sanitary logging to remove dead or dying trees which are flammable material etc.).
- Law enforcement and surveillance measures (regular patrols in the forest area) to prevent arson, early detect and immediate extinct fire outbreaks.
- Raise public awareness (mainly targeted to forest area visitors) regarding fire risks.

Early detection measures

- Establishment of an adequate network of fire observatories suitably equipped with sighting, alarm and communication instruments and adequately staffed.
- Establishment and/or improvement of electronic means of communication, regarding early warning and rapid response systems (mobile phones etc.)

Management and suppression measures

- Coordination of actions, especially at local level, for the early fire fighting and suppression.
- Appropriate management of means and personnel in order to arrive at the fire outbreak, up to 15 minutes following its first announcement.

Sanitary loggings at the National Park of Parnitha, Central Greece
EKBY Photo Archive/L. Logothetis

4.3.2.5. Pathogens

Under climate change, forest management should aim at the strengthening of forest ecosystems against pathogens (fungi and insects) on one hand and at the immediate control of such outbreaks in order to prevent expansion to adjacent areas, on the other. Specifically, as in the case of forest fires, Forest Management Plans should incorporate a number of measures regarding prevention, early detection and immediate suppression of such phenomena, in order to exterminate or reduce the pathogens' populations at acceptable levels.

- Preservation of tree and stand vitality to increase resistance to pathogen outbreaks (e.g. thinning aiming to reduce water stress, favoring of mixed stands, selection or favoring of genotypes and varieties, minimization of injuries to trees during silvicultural treatments etc.).
- Implementation of prevention and protection measures in order to avoid introduction or reduce transfer risk of pathogens carried by humans, domestic animals and heavy equipment.
- Training of forest workers regarding a) application of good phytosanitary practices (e.g. use of gloves when handling seeds and seedlings) to reduce the risk of disease spread and b) early detection and management of outbreaks caused by pathogens.
- Monitoring for the early detection and assessment of the severity degree of pathogens' outbreaks, identification and mapping of forest areas which are considered to be vulnerable to or already suffer from such outbreaks.
- Immediate implementation of sanitary loggings to remove affected trees or trees with disturbed physiology and proper disposal of timber products coming from sanitary logging and other silvicultural treatments (e.g. debarkment of logged trees and exposure to direct sunlight and air to exterminate pathogens' larvae etc.), in order to reduce outbreak risk.

4.3.2.6. Extreme weather events

As a result of climate change, the frequency and/or intensity of extreme weather events such as heavy precipitation, strong winds, storms etc. is expected to increase. To reduce the risks caused by such extreme phenomena, the implementation of prevention measures is needed. It is noted that measures for the prevention against floods and soil erosion are indicated in chapter 4.3.2.3. Water and ground resources.

- Favoring of uneven-aged stands of selective or group selective silvicultural system and favoring of wind-resistant species, especially at the edge of stands with open space.
- Preservation or increase of species diversity and diversity of functional types in forest ecosystems, in order to increase resistance to storm breakage.
- Favoring of hardwood species against conifers to reduce the risk of breakage from snow and ice, in areas facing increased snowfalls and ice storms.
- Adaptation of rotation period to minimize the risk of damage caused by storms (e.g. landslides due to reduced vegetation cover).
- Afforestation and reforestation to provide windshield protection in adjacent (to forests) areas (e.g. through the creation of windbreaks).

EKBY Photo Archive/L. Logothetis

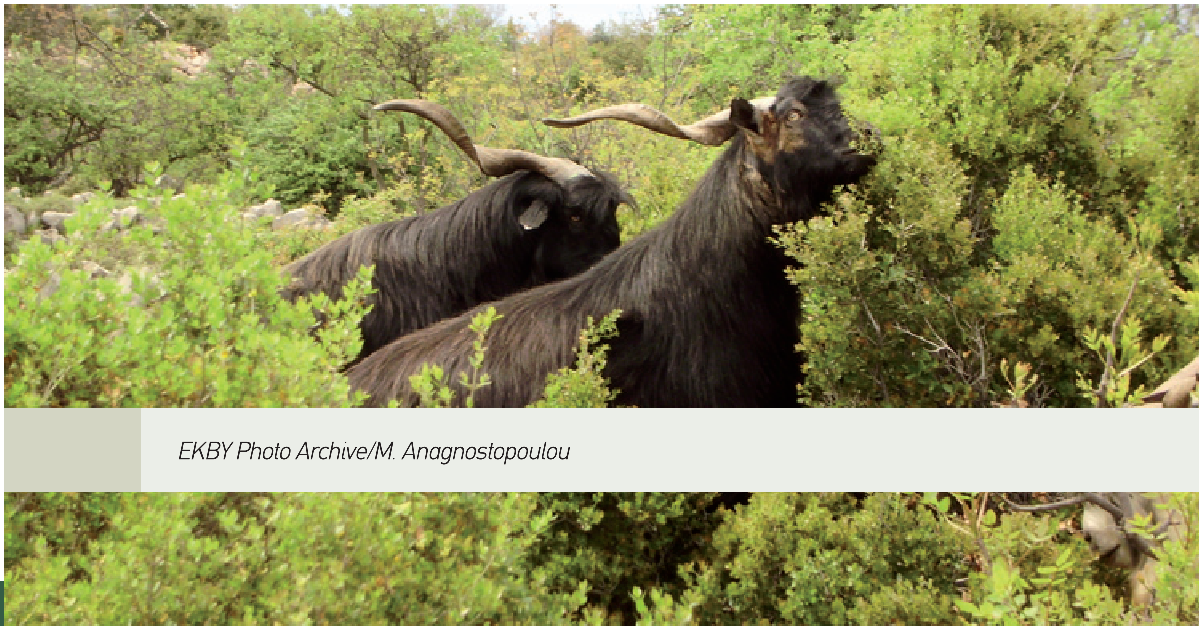
4.3.3. Adaptation measures for the main forest ecosystems in Greece

The present chapter outlines the measures that need to be taken for the adaptation of forest management in the main Greek forest ecosystems, per vegetation zone. These measures aim to reduce ecosystem vulnerability against climate change and at the same time to enhance the functions and services that forests provide to humans (protection from erosion, regulation of water runoff etc.). Besides, many of these measures are beneficial for biodiversity and they also contribute to the mitigation of climate change.

4.3.3.1. Mediterranean (Thermomediterannean - Eumediterranean) vegetation zone

Evergreen broadleaved shrubs zone: Evergreen broadleaved shrubs, either as low, sparse shrubs or as high shrubs, cover ~20% of the country's total surface area. This zone exhibits high inter- and intraspecific diversity and is characterized by a wide ecological tolerance breadth as it comprises of drought-tolerant species and species adapted to low soil fertility. The rehabilitation of these shrubs, using a natural method and not by changing species composition, could significantly improve the provided services as regards regulation of water runoff and storage, protection from soil erosion and desertification, increase in the sequestration and storage capacity of CO_2, improvement of the landscape aesthetic value, as well as production of firewood and charcoal of excellent quality. Therefore, the proposed adaptation measures to enhance the role of shrubs in the face of climate change are:

- Regulation of grazing pressure, aiming to reduce overgrazing on one hand and to avoid formation of dense vegetation which faces high fire risk, on the other.
- Implementation of prevention measures against forest fires.
- Implementation of appropriate silvicultural treatments (tending, inversion thinning) and extension of rotation period (up to 150-200 years) for the inversion of high shrubs into high forests (to be applied following inversion of low, sparse shrubs to high, dense shrubs).



EKBY Photo Archive/M. Anagnostopoulou

Phrygana zone: This zone (a typical East Mediterranean zone of cushion-like spiny semifruticose shrubs) exhibits high biodiversity and includes many endemic species. Phrygana are composed by drought-tolerant species since they are able to survive in almost semi-desert conditions. Their key role, regarding protection from climate change impacts, lies mainly in their action against erosion and desertification of the already poor soils they occupy. Furthermore, under suitable conditions, their natural rehabilitation can lead to an increase of CO_2 sequestration and storage capacity. The proposed management measures for phrygana formations are:

- Limitation of fragmentation due to anthropogenic activities (e.g. construction activities and works, especially on islands and coastal landscapes).
- Regulation of grazing activities through the development and implementation of management plans for grazed areas and cattle adapted livestock breeds.

Aleppo and Aegean pine forests: Aleppo and Aegean pine forests cover approximately 17% of the country's forest surface area and exhibit great aesthetic value as they are distributed to highly touristic areas. Their ecological value is also significant, since they create a rich understory, they are tolerant to a wide range of environmental conditions and, most importantly, they are well adapted to forest fires and their regeneration, following this form of disturbance, is easy. However, nowadays the main pressures and threats for Aleppo and Aegean pine forests are forest fires and land use changes (i.e. touristic infrastructure, such as hotels etc.). Unfortunately, these two kinds of pressures are often exerted in combination, as the distribution areas of these two species are considered to be of great economical value. The enhancement of their role to face climate change lies in the conservation and improvement of the natural forests' structure and in the expansion (through reforestations) of these pine species' artificial forests. In the above context, the proposed management measures are:

- Planning and implementation of measures for the prevention, early detection and immediate control, management and suppression of forest fires (e.g. policing patrols, removal of dead biomass along frequented roads and paths, construction and maintenance of water reservoirs, maintenance of road network accessibility etc.).
- Implementation of silvicultural treatments, i.e. thinning and pruning during the early stages of forest stands when tree density is high, in young forests created through natural regeneration or reforestation, following a fire incident.
- In Aleppo pine forests, preservation of the understory in order to prevent a) epidemic outbreaks of the pine processionary moth (*Thaumatopaea pityocampa*)[37] and b) the creation of mycogen plate (as litter of understory species contributes to the faster decomposition of needles), which is highly fire-prone and may cause extended forest fire incidents.
- For Aegean pine forests, the rehabilitation of degraded shrubs or the restoration of degraded soils through plantings (using propagation material of appropriate, as adjacent as possible, origin), aiming to improve the provided services and increase the sequestration and storage capacity of CO_2.

37. The larvae of this moth form rows (processions) before entering the ground for pupation. The understory shrubs cause breaking of these processions and as a result the larvae lose their orientation and eventually die.

4.3.3.2. Supramediterranean subcontinental zone (oak forest zone)

Coppice deciduous broadleaved forests (mainly oak forests): Deciduous broadleaved forests play a significant role at the regulation of water regime, substantially contributing to the reduction of surface runoff but mainly to water storage, since during precipitation seasons (autumn, winter, spring) they bare no foliage and therefore can retain only a very small amount of water on their crown. This fact, combined with their large distribution area and the high biodiversity they exhibit, attaches significant ecological, aesthetic, protective and economic value to oak forests. Accordingly, their role in the mitigation of climate change is also significant and may be further enhanced through their inversion to high forests. The latter is also expected to lead to the production of more valuable timber (larger in size and of greater economic value). The proposed adaptation measures, which can at the same time enhance the role of these forests in mitigating climate change, are:

- Cessation/reduction of clear cuts and of extraction of small diameter wood in order to avoid erosion and degradation of its quality (due to the permanent removal of inorganic nutrients from the ecosystem).
- Gradual inversion of coppice forests to high forests[38], through selective inversion thinning (positive selection) and extension of rotation period from 30 years (currently applying), to 100-150 years.
- Preservation of the understory and middle level floor vegetation, where applicable, aiming to shade the soil and tree trunk to prevent the creation of greedy branches.
- The above measures apply to high quality sites. In low quality sites, natural rehabilitation of forest stands, through cessation of loggings and extension of rotation period from 30 to 120 years, is considered necessary.
- Characterization of Turkey oak forests (*Quercus cerris*) distributed on limestone, steep slopes as protective forests and cessation of any other activity.
- Artificial expansion of their distribution through seeding or planting in areas with suitable ecological conditions, especially in areas affected by fires (Valonia oak, Macedonian oak, Euboean oak, Downy oak and Pedunculate oak) or use of these tree species mainly as ornamental in gardens, parks and tree stands (Aleppo oak, Pedunculate oak).
- Preservation of traditional oak silvopastoral systems (40-60% oak cover in shrubs and woods) due to their high biodiversity value and increased water infiltration rates.

38. Wood production throughout the rehabilitation and restoration period will come, to a large extent, from the material of tending inversion thinning. Thinning should be very intense at the beginning (20-25% of trees) because oak trees need space to develop their crown.

4.3.3.3. Zone of Mediterranean montane conifers

<u>*Greek and Bulgarian fir forests*</u>: Fir forests have many functions and provide multiple services to humans (water regulation, soil protection, wood and other products supply etc.) and significantly contribute to the mitigation of climate change through their ability to sequestrate and store CO_2. The adaptation of these forests' management to climate change can be achieved through their conservation and expansion, as far as possible. The proposed management measures for fir forests are:

- Implementation of selective or group selective silvicultural system in groups and thickets of various diameters with no spatial pattern, aiming to improve growing stock and harvest, regulate structure (age and diameter distribution), favor natural regeneration etc.
- Increase of mature diameter logging aiming to increase growing stock and to achieve larger timber dimensions, as well as higher amounts of carbon storage.
- Enrichment with timber valuable broadleaves, in sporadic mixture of 10-20% of the surface area, in order to facilitate humification of needles, improve soil conditions, enhance natural regeneration of fir and reduce the risk of bark beetle outbreaks.
- In case of bark beetle outbreaks, implementation of sanitary logging and simultaneous cessation of all scheduled logging activities; debarkment of logged trees to exterminate harmful insect larvae (exposure to air and direct sunlight).

Greek fir forest in Oiti, Central Greece
EKBY Photo Archive/L. Logothetis

Black pine forest
EKBY Photo Archive/L. Logothetis

Black pine forests: Black pine is a long-lived species with wide ecological tolerance limits. This species creates extensive in size, rich in timber forests with high growing stocks, even in relatively poor soils. Black pine forests provide multiple services to humans and play a key role to the conservation of biodiversity. Apart from the above, they have the ability to affect local climate conditions (amelioration of high temperatures, increase of relative humidity). Finally, depending on their age, they play an important role to sequestration and storage capacity of CO_2. The proposed management measures for Black pine forests are:

- Extension of rotation period as much as possible to achieve the production of larger in size (dimensions) timber.
- Cultivation in the phase of thin and coarse bark with positive selection thinning and pruning up to ~8m height, positive selection thinning in the phase of thin barks and over-thinning in the phase of medium barks, aiming to reduce conversion risk of ground to crown fire[39] and to reach production of valuable wood.
- Favoring of sporadic mixture with timber valuable broadleaved species capable to improve soil quality, such as Bosnian maple, Hornbeam, European hornbeam etc.
- Wider use of Black pine at reforestations on montane regions, as well as for the rehabilitation of degraded oak forests.
- Use of Black pine for elevating treeline in Central and South Greece, aiming at the production of water through the deceleration of snow melting by 3-4 weeks.

39. Black pine is not adapted to crown fires and is not naturally regenerated following such disturbances. However, it is well adapted to ground fires due to its thick bark, and its natural regeneration after such fires is enhanced as the mycogen plate created by its needles, is destructed.

4.3.3.4. Zone of temperate broadleaved deciduous forests

Beech forests: Beech is one of the main forest species in Europe. It is shade-tolerant (more than any other broadleaved species) and tolerant to very low temperatures. In Greece, the natural regeneration of beech is considered to be easy due to the species' fruiting frequency (full fruiting per 4-5 years), which depends on summer weather conditions (flowering period). Beech forests are very important both in terms of ecology (as they provide habitat for small and big mammals, bird species and other fauna and flora species) and aesthetics, since they are among the most beautiful Greek forests. In addition, beech forests provide multiple services to humans, the most important of which is the production of water of good quality. To enhance the above functions and services provided by beech forests and increase their adaptation to climate change, the following management measures are proposed:

- Inversion of coppice to high forests through selective inversion thinning and extension of rotation period from 40 to 100 years.
- Implementation of uneven-aged, group selective silvicultural forms which are close to the form of a high forest, in groups or thickets, without spatial strict order, through regeneration (inter-progressive or verge logging).
- Implementation of negative selection against multi-fork trees from the early stages and then positive selection by favoring the best trees with single upright stem. In later phases, only positive selection applies and only in the overstory (high thinning). After the stand enters the understory initiation phase and until the final logging, no other intervention should be applied.
- Enhancement and acceleration of the regeneration in overmature stands or stands being in a crucial phase regarding the maintenance of their structure as forests.
- Afforestation of selected gaps, with timber valuable species, such as sycamore.

Beech forest on Mount Olympus, NC Greece
EKBY Photo Archive/L. Logothetis

4.3.3.5. Zone of high Oro-mediterranean and subalpine conifers

Cold tolerant species (Scots pine, Heldreich's pine, Macedonian pine, Norway spruce and birch): The species that compose the cold tolerant conifers zone are adapted to very low temperatures (even below -30 °C) and to a relatively short growing period. They are very productive in high quality sites and produce valuable timber. Norway spruce, in particular, forms the most productive forests of Greece with its growing stock exceeding 1.000 m^3 / ha and its tree height reaching above 50 m. These forests exhibit great economic but also high ecological value. In the past, grazing and illegal logging have been the main pressures for these forests. Nowadays, the intensity of these pressures is reduced; however, they continue to pose a threat to forests. As in Greece these species mainly distribute in their thermal-tolerance limits (the southern distribution limit in Europe for Norway spruce and Scots pine) they may be vulnerable even to small climate alterations. Forests management measures to enhance adaptation of these species to climate change include:

- Preservation of the high genetic diversity (Scots pine, Norway spruce), through exception of certain stands or parts of stands (of 2-3 ha in size), which exhibit intense genetic dimorphism, from wood harvesting.
- Implementation of protection measures to prevent and suppress pathogens' outbreaks, mainly fungi and bark beetles (Scots pine).
- Regulation of grazing and more intense surveillance to prevent illegal logging.
- Facilitation of natural regeneration, plantings or seedings, for elevating treeline in North Greece, aiming to decelerate erosion and to increase water absorption to the aquifers (water production).

Norway spruce forest in Elatia, NE Greece
EKBY Photo Archive/M. Katsakiori

4.3.4. General measures

4.3.4.1. Socio-economic measures

Adaptation of forests to climate change should take into account, not only ecological data, but also the social needs of forest-dependent communities[40]. Furthermore, the economic aspect of such management decisions should also be considered prior to their implementation (e.g. the future development of market trends for forest products due to climate change should be taken into account)[41].

More specifically, climate change is expected to cause degradation of the services provided by forests and this is expected to affect directly or indirectly human societies. Populations that live or work in areas adjacent to forests, therefore depend on forests for goods, jobs and other services, are more susceptible to these impacts. Many urban areas depend as well, directly or indirectly on the forest ecosystem services, such as water supply and recreation. Therefore, the integration of social parameters in the adaptation of forest management planning is of vital importance.

In the above context, awareness raising of local societies regarding the causes and the social and economic impacts of climate change should be encouraged and forest management should provide opportunities for income and jobs from the forest sector. These opportunities should focus on advancing local forest companies specializing in processing of timber and other wood and non-wood forest products, the development of ecotouristic activities etc. At the same time, new markets should be opened, new forest products should be designed and produced and distribution of forest products should also use alternative channels. In conclusion, forest management should be adapted to meet the needs and demands of the local communities; however, at the same time, the forest should be protected against illegal activities, such as conversion of forests into agricultural land, illegal logging and hunting activities etc.

EKBY Photo Archive/L. Logothetis

40. Heller, N.E. and E.S. Zavaleta. 2009. Biodiversity management in the face of climate change: A review of 22 years of recommendations. *Biol. Conserv.*, 142: 14-32.

41. Perez-Garcia, J., Joyce, L.A., McGuire, A.D. and X. Xia. 2002. Impacts of climate change on the global forest sector. *Climatic Change*, 54: 439-461.

4.3.4.2. Administrative measures

The empowerment of public administration at national, regional and local level is necessary for the effective adaptation of forest management to climate change. The proposed measures towards this direction are:

- Provision of the necessary means to Forest Services, including adequate staffing, continuous training of personnel, availability of the necessary equipment and scientific / technical tools, adequate funding at national, regional and local level.
- Development of mechanisms for the exchange of good practices and the dissemination of information regarding adaptation of forest management to climate change.
- Implementation of monitoring and integration of research results to forest management.
- Enhancement of the competent Forest Services to control and eliminate illegal activities and reduce pressures and threats to forest ecosystems.

Forest landscape on Mount Parnonas, Peloponnese
EKBY Photo Archive/L. Logothetis

LIFE+ AdaptFor:
STEP 2 - Design of Adaption Measures

In the framework of the LIFE+ AdaptFor Project, the proposed adaptation measures regarding management practices aim at the reduction of forest ecosystems' vulnerability and at the strengthening of their resilience to climate change. Furthermore, they include instructions on how to address emergency issues such as insect outbreaks, droughts etc. During the design of adaptation measures (general and specific measures), the following have been taken into account:

- the results of the vulnerability assessment of the four forest ecosystems to the impacts of climate change
- the management needs of the four forest ecosystems
- International literature (review of adaptation measures to climate change, which apply to similar forest ecosystems around the world)
- practical issues such as the applicability of measures, in terms of cost and the public acceptance
- the conservation and protection needs of forest biodiversity, according to the principals of close-to-nature silviculture[42]
- the guidelines of the European Commission on dealing with the impacts of climate change on the management of the NATURA 2000 Network[43], since all study areas overlap with NATURA 2000 Network sites
- data (management practices and measures) from the current and previous Forest Management Plans of the four study areas
- expertise and experience of local competent authorities
- the results/comments received during a) the public consultation on the Project website and b) the consultation meeting with the competent Forest Services (local and central).

Based on the above, the specific management objectives for each study area have been set. To achieve these objectives, management measures for the adaptation of forest management to climate change have been drafted. The measures have been actually based on close-to-nature silvicultural practices and aim at the enhancement of forest productivity and ecosystem services. At the same time, these measures aim at the conservation of biodiversity and structural diversity, the availability of water, the enhancement of regeneration, the protection of soil, the promotion of ecosystem heterogeneity and the increase in connectivity[44]. The proposed adaptation measures will eventually render the ecosystems less vulnerable and will also contribute to the mitigation of climate change through an increase of the sequestration and storage capacity of CO_2. Mostly, "low or no-regret" measures were adopted to address the uncertainties.

42. See for example https://prosilvaeurope.wordpress.com/prosilva-forestry-principles-2012-2.

43. European Union. 2013. Guidelines on Climate Change and Natura 2000. Dealing with the impact of climate change on the management of the Natura 2000 Network of areas of high biodiversity value, http://ec.europa.eu/environment/nature/climatechange/pdf/Guidance%20document.pdf(2013). Accessed 2 February 2013.

44. Jactel, H., Nicoll B.C., Branco, M., Gonzalez-Olabarria, J.R., Grodzki, W., Langstrom, B., Moreira, F., Netherer, S., Orazio, C., Piou, D., Santos, H., Schelhaas, M.J., Tojic, K. and F. Vodde. 2009. The influences of forest stand management on biotic and abiotic risks of damage. *Ann For Sci*, 66:(701) 1-18.

The proposed measures, shown in the Table below, are divided into the following categories: a) short-term adaptation measures (S) to be implemented immediately in order to control the occurring phenomena at the four study areas, b) medium and long-term adaptation measures (M-L) for the enhancement of forest ecosystems under the effects of climate change and c) supplementary measures (SU) required for the success of the adaptation measures and for the protection of forests against biotic and abiotic factors. Briefly, per study area:

Ritini-Vria Forest at Mount Pieria: Suspension of all scheduled logging and immediate logging of dead trees in order to avoid similar epidemic incidents over the following years. Logged trees should be debarked as soon as possible and exhibited to direct sunlight and air to exterminate bark beetle larvae. Finally, regeneration, aiming at the preservation of this valuable, to Greece and Europe, Scots pine population, should be encouraged and protected.

Aspropotamos-Kalampaka Forest: Enhancement of the broadleaved species forest ecosystem in medium or poor quality sites, i.e. extension of the rotation period for broadleaved species, in combination with selective thinning to produce more valuable timber and wood products. On the contrary, in good quality sites, the favoring of fir (invasive species) through the implementation of selective or group selective silvicultural form by positive selection techniques has been recommended.

National Park of Parnitha: Implementation of sanitary logging to reduce the infectious potential, followed by restoration of the forest ecosystem (mainly through planting of four-year old Greek fir seedlings). In marginal sites, replacement of fir with other local forest species, more drought-tolerant and less demanding regarding soil conditions, such as Prickly juniper (*Juniperus oxycedrus*) or Downy oak (*Quercus pubescens*).

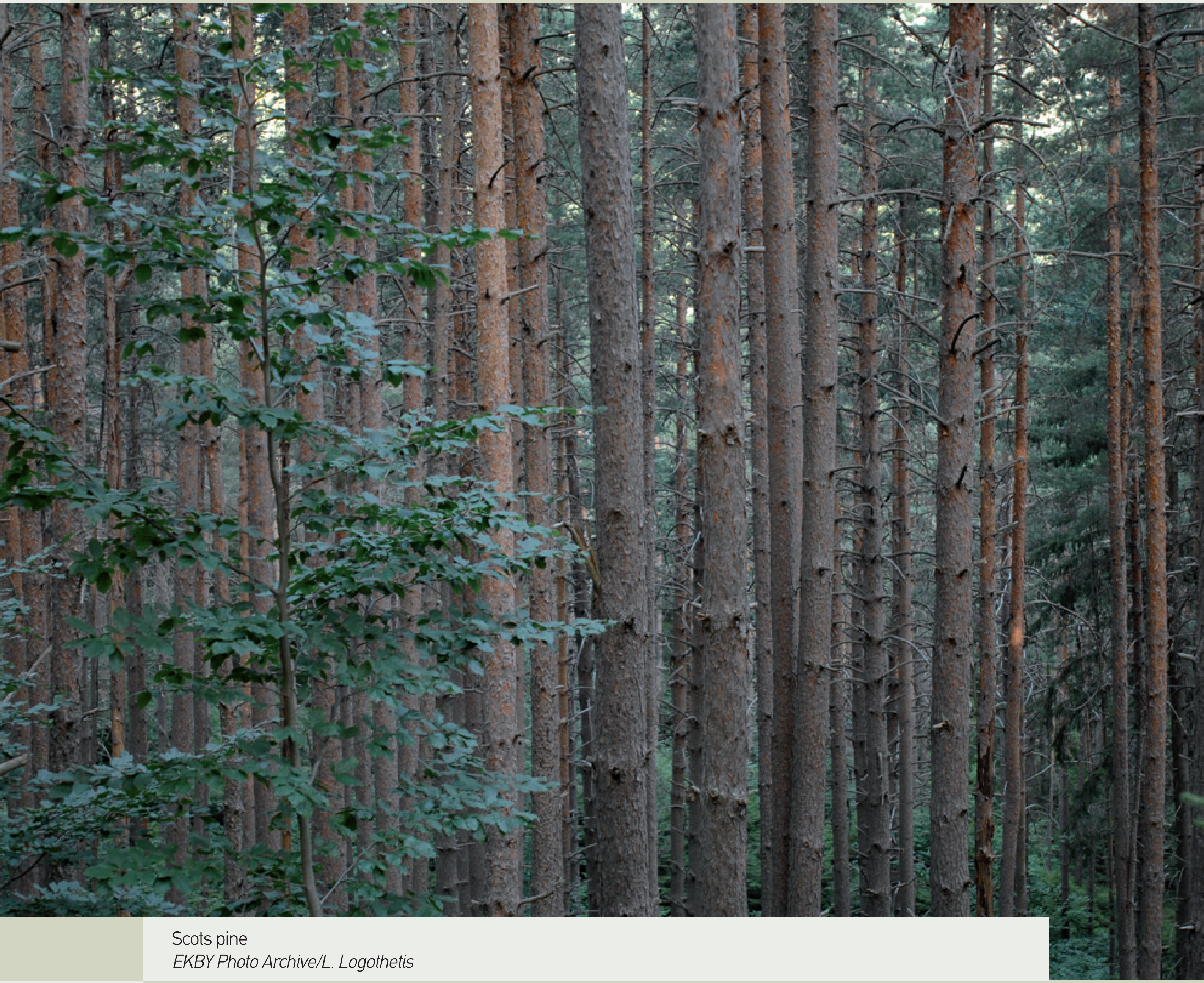
Mount Taygetos: Logging of infected trees and implementation of the selective silvicultural form, which meets the requirements of adaptation management to climate change, as it leads to the creation of more stable high forests with higher growing stock, and greater sequestration and storage capacity of CO_2. Finally, the encouragement and protection of regeneration, aiming at the preservation of this valuable Greek fir population is proposed.

The proposed measures have been further specified at stand level and subsequently integrated into the Forest Management Plans covering each of the four study areas.

Study area	Management objective	Measure	Detailed description
Ritini-Vria Forest at Mount Pieria	Conservation of Scots pine forest	Immediate logging of dead or dying trees (sanitary logging) (S)	Logging of Scots pine trees infected by bark beetles or by the fungus *Peridermium pini*.
		Establishment of pheromone trap network (S)	Use of suitable attractant substances to trap harmful insects. Alternatively, conversion of infected trees to tree traps.
		Enhancement and protection of regeneration (either natural regeneration or through seeding/planting) (M-L)	Encouragement of regeneration should focus on logged (due to increased mortality rate) stands, on remaining stands with insufficient regeneration and also on large areas covered by dense herbaceous vegetation. Fencing of surface areas under regeneration processes is required due to grazing pressure.
		Favoring of mixed stands (M-L)	Mixed stands comprised of Scots pine with fir and beech should be favored in the area, especially at sites where the infectious potential (caused by the fungus and bark beetles) is high.
	Conservation of Scots pine genetic diversity	Preservation of the dominant species subpopulations in the area (M-L)	Selection and preservation (e.g. seed bank) of propagating material and/or establishment of seed orchards using the above material.
Aspropotamos-Kalampaka Forest	Rehabilitation of mixed oak forest and chestnut forest at medium / poor quality sites	Immediate logging of dead or dying trees (sanitary logging) (S)	Removal of fir (invasive species) to prevent further bark beetle outbreaks, to reduce competition between fir and oak and to enhance the deciduous oak forest, providing multiple benefits to the ecosystem (retention of water etc.).
		Favoring of mixed stands (M-L)	Mixed stands comprised of Hungarian oak (*Quercus frainetto*) and Bulgarian fir (*Abies borisii regis*) or Turkey oak (*Quercus cerris*) and Bulgarian fir or beech and fir. Also, the conservation of chestnut (*Castanea sativa*) is important for the area as the species is known to improve soil conditions (at poor, shallow and marginal sites) and enhances the income of locals (providing timber and commercially exploitable fruits).
		Cessation of clear cuts to broadleaved forests (M-L)	This measure aims at the protection of soil productivity, the reduction of erosion and degradation risk. At the same time, selective thinning should be applied in order to reduce disturbance risks, such as forest fires.
		Extension of rotation period (M-L)	Extension of rotation period from 30 to 120-150 years for oak and chestnut forests and inversion of the forest to high forest (higher sequestration and storage of CO_2).
		Application of selective logging and thinning (M-L)	Application of selective thinning and logging every 8-10 years on the overstory. Conservation and enhancement of the under and middle level floor (consisting of soil-improving species), to strengthen biodiversity and soil productivity.
	Favoring of fir at good quality sites	Application of selective logging and thinning (M-L)	Favoring of fir stands with gradual removal of the Turkey oak overstory is recommended. Implementation of the selective silvicultural form through positive selection.

Study area	Management objective	Measure	Detailed description
National Park of Parnitha	Conservation of Greek fir at good quality sites	Immediate logging of dead or dying trees (sanitary logging) (S)	Logging of fir trees which are infected by bark beetles or exhibit discrepancies and errors (in terms of morphology and physiology), since they are considered to be at greater risk of necrosis due to climate change.
		Establishment of pheromone trap network (S)	Use of suitable attractant substances to trap harmful insects. Alternatively, conversion of infected trees to tree traps.
		Enhancement and protection of regeneration (either natural regeneration or through seeding/planting) (M-L)	Planting of four-year old fir seedlings has already been applied in the area with great success (restoration after 2007 forest fire). In the 2nd year after planting, survival amounted to 70-80%.
		Application of selective thinning and logging (M-L)	Intensification of thinning in order to improve water balance and to mitigate the negative effects of drought.
	Replacement of Greek fir in degraded soils	Changes in species composition (M-L)	In marginal sites, replacement of fir with other local forest species, more drought-tolerant and less demanding regarding soil conditions, such as Prickly juniper (*Juniperus oxycedrus*) or Downy oak (*Quercus pubescens*).
Mount Taygetos	Conservation of Greek fir forest	Immediate logging of dead or dying trees (sanitary logging) (S)	Removal of fir trees infected by bark beetles to improve the stand health and reduce competition.
		Establishment of pheromone trap network (S)	Use of suitable attractant substances to trap harmful insects. Alternatively, conversion of infected trees to tree traps.
		Enhancement and protection of regeneration (either natural regeneration or through seeding/planting) (M-L)	Following sanitary logging, gaps in the forest should be reforested either by favoring natural regeneration or by planting two-year old fir seedlings.
		Favoring of mixed stands (M-L)	Favoring of mixed fir-Black pine-chestnut stands (depending on the location). Black pine, in particular, plays a significant ecological role, acting as a pioneer species entering fir forests following disturbances, but also as a species of the climax vegetation community at good quality sites.
		Application of selective thinning and logging (M-L)	Favoring of fir stands under single-selection silvicultural form to increase tree diameter up to 70-80 cm.
	Conservation of Greek fir genetic diversity	Preservation of the dominant species genetic diversity in the area (M-L)	Selection and preservation (e.g. seed bank) of propagating material and/or establishment of seed orchards using the above material.

Study area	Management objective	Measure	Detailed description
ALL AREAS	Protection of forests against other biotic and abiotic factors	Limitation of grazing by wild and domestic animals (SU)	Reduction of grazing pressure (which has negative impact on the regeneration of forest stands) through fencing for the protection against domestic animals (e.g. in the case of Ritini-Vria Scots pine forest) or through regulating wild animal populations (e.g. in the case of Greek fir forest at the National Park of Parnitha).
		Preventive and repressive measures against forest fires (SU)	Application of preventive (e.g. silvicultural treatments such as thinning, branch pruning, understory vegetation removal and disposal of the debris to locals) and repressive measures (e.g. fire protection infrastructure maintenance and enforcement such as firebreaks, roads, reservoirs, fire stations etc.) as both frequency and intensity of forest fires is expected to increase as a result of climate change.
		Gradual afforestation of forest roads (which are no longer used) (SU)	Afforestation of decommissioned forest roads to reduce fragmentation of forest vegetation.
		Protection of soil resources during the application of silvicultural treatments (SU)	The protection of soil resources is highly prioritized in the mountainous Greek forests. For this reason the following are proposed: a) avoidance of management methods that destroy or seriously disturb the forest floor, especially in areas where the soil has a low infiltration rate, b) proper selection of means for wood extraction and c) training of logging crews.
	Research and awareness	Establishment of permanent monitoring program (SU)	Establishment of 16 permanent sampling plots (four plots/area) to monitor stand structure and soil attributes. Special emphasis is given on the monitoring of the dominant vegetation species and vegetation structures/units, as they are deemed to be indicators of the ecological conditions' alterations under the effects of climate change. In addition, installation of a telemetric meteorological station per study area for the monitoring of climate parameters (temperature, precipitation etc.).
		Training of stakeholders and public awareness (SU)	Training seminars for the personnel of local Forest Services and public awareness through educational programs and participatory actions regarding the protection of the natural environment.



Scots pine
EKBY Photo Archive/L. Logothetis

5 Monitoring, review and revision

The adaptation of forest management is a dynamic process. The implementation of management measures is constantly subjected to monitoring and the results of this monitoring are used to continuously adjust and revise management practices[45]. Besides, the fact that climate change contains multiple uncertainty factors renders the adaptation of forest management a more or less "learning by doing" procedure[46].

45. Bolte, A., Ammer, A., Löf, M., Madsen, P., Nabuurs, G.-J., Schall, P., Spathelf, P. and J. Rock. 2009. Adaptive forest management in central Europe: Climate change impacts, strategies and integrative concept. *Scand. J. Forest Res.* 24(6): 473-482.
46. Bodin, P. and B.L.B. Wiman. 2007. The usefulness of stability concepts in forest management when coping with increasing climate uncertainties. *Forest Ecol. Manag.* 242: 541-552.

Field work
EKBY Photo Archive/V. Chrysopolitou

In the above context, during and following the vulnerability assessment and the design and subsequent implementation of adaptation measures to climate change, an integral part of the forest management is the monitoring of:

a) changes in climate parameters,

b) the most important climate change impacts to forests, especially to the most vulnerable ones and

c) the effectiveness/success of management measures already implemented for adaptation to climate change.

In this way, the monitoring results and the experience gained are constantly integrated in the design and implementation of forest management. In some cases, it is necessary to take into account and monitor also the social and economic impacts of the implementation of adaptation measures.

The monitoring methods to be applied for assessing the impacts of climate change, depend on both the forest ecosystem's vulnerability and practical issues such as the available budget and equipment, the personnel in charge of the monitoring, the spatial scale of monitoring etc. For example, monitoring can be performed using remote sensing (interpretation of satellite images, change detection techniques), through the establishment of permanent sampling plots or even through a simple inventory *in situ*. In any case, the limits of the forest area to be monitored should be precisely defined.

The most important step during the design of the monitoring program is the selection of the appropriate parameters/indicators. Indicators should represent the changes monitored (impacts of climate change on forest ecosystems), provide information on the causes of these changes (diagnosis of the causes) and be easily identified and recorded, even by non-scientific personnel. For example, in order to monitor the impacts of climate change to the biodiversity of a forest ecosystem, it is advisable to select, as indicators, the most vulnerable species or vegetation types to changes in temperature or precipitation.

Data sampling on Mount Pieria, NC Greece
EKBY Photo Archive/G. Poulis

Data sampling in Parnitha, Central Greece
EKBY Photo Archive/V. Chrysopolitou

The monitoring frequency is defined separately for each of the monitoring parameters. Indicatively, the record of meteorological data may be performed on a monthly or daily basis, while regarding vegetation data or parameters related to forest health (e.g. pathogens) once per year should be enough. The frequency may be modified depending on the results of the monitoring (e.g. in case a change happens faster than originally estimated and the impact is significant, then the monitoring frequency of the respective parameters should be increased).

Monitoring should be applicable at local level and should be consistent with the available financial and human resources and tools of each competent Forest Service. As mentioned above, the monitoring program should be designed in such a way that field data can be acquired even by technical personnel, without specialized scientific training. However, in some cases, the monitoring of specific parameters (e.g. pathogens such as insects and fungi, vegetation types etc.) may require the support of other state or regional services or other bodies (e.g. research or academic institutes).

Monitoring may lead to the review and subsequent revision of the Forest Management Plans. Even though the duration that these management plans are in force is defined, it is possible, in case of severe disturbance that has appeared or is highly likely to appear, that the management plan is revised in order to incorporate changes in forest management, as a result of monitoring.

LIFE+ AdaptFor:
STEP 3 - Establishment of a permanent Monitoring Program

In the framework of the Project LIFE+ AdaptFor, a permanent monitoring program has been established at the four study areas, aiming at the monitoring of:

a) the meteorological parameters which are indicative of climate change,

b) the impacts of climate change, i.e. the course of coniferous species' dieback and of the intrusion of conifers into broadleaved forests and

c) the success of the proposed adaptation management measures.

In each of the study areas, four monitoring plots, of 0,2 ha each, have been established. The selection of these sampling plots has been based on a) the representativity of the environmental conditions' diversity in each area, i.e. the different site quality/productivity (as defined according to the different vegetation units found in the areas) and b) the existence of baseline data from previous studies. Within the monitoring plots, each tree has been permanently marked with a unique identifier for its rapid identification and correlation with previous data collected. From each sampling plot, a number of silvicultural and soil parameters and parameters related to vegetation, structure, tree growth and forest health are measured, using standard methods[47]. These parameters are:

- Height, diameter at breast height of individual standing trees.
- Height from the ground to tree crown.
- Cover of understory vegetation or herbaceous vegetation.
- Extent of canopy closure.
- Percentage of bare soil.
- Depth of humus and litter.

Specifically, in each sampling plot, an inventory of standing trees (live and dead), decumbent (dead) trees, shrubs and regeneration is proposed. The assessment of tree vitality results from the degree of defoliation in the upper 1/3 of the tree crown and is performed through visual observation, based on the criteria of the International Cooperation Program for Forests (ICP Forests). The degree of decomposition is estimated both for decumbent and standing dead trees using a 5-degree scale which uses as diagnostic characteristics the tree bark, thin twigs, texture, shape, wood color and distance of tree trunk from the ground (Daskalakou *et al.* 2008[48]).

47. Tsiaoussi Vasiliki, Vasiliki Chrysopolitou and S. Dafis (editors). 2012. Specifications for the monitoring of climate change impacts at the four forest ecosystems of the project LIFE+ AdaptFor. Greek Biotope-Wetland Centre (EKBY). Thermi. 35p + Annex. http://www.life-adaptfor.gr/assets/adaptfor-files/Paradoteo_Drasi_6.pdf

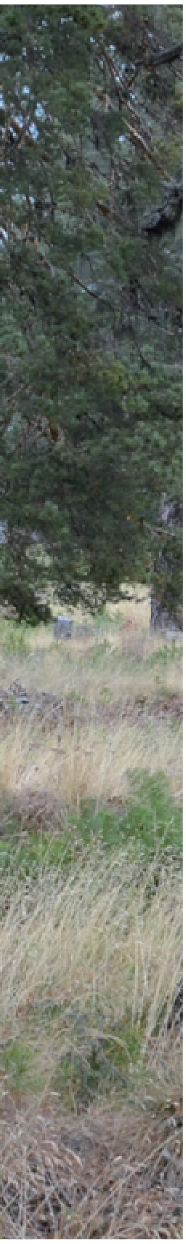
48. Daskalakou, E.N, Karetsos, G, Tsagkari, K, Vasilopoulos, G. and G. Baloutsos. 2008. Preliminary results regarding the assessment of deadwood as a biodiversity index at four representative forest ecosystems in Greece. *Forest research*, 21: 15-28 (*in Greek*).

Furthermore, apart from the above basic parameters, the monitoring of some additional monitoring parameters has been proposed. These additional parameters include the understory vegetation units, as well as other parameters regarding forest health, such as pathogens (establishment of pheromone traps and identification of samples in the laboratory), periodic mapping of affected and dead trees due to the action of bark beetles and fungi, assessment of the severity of infection degree in the sampling plots etc.

Finally, in each pilot area a telemetric meteorological station has been installed for the measurement, record and automatic dispatch (to the competent Forest Services) of the following parameters:

- Air temperature (°C).
- Relative air humidity (%).
- Precipitation (mm).
- Sunshine duration (min).
- Total solar radiation (W/m^2).
- Diffused solar radiation (W/m^2).
- Wind speed (m/s).
- Wind direction.

The collection of data from the sampling plots is performed once per year (in May) by the personnel of the local Forest Services (row data). Following their processing, the data are sent to the Directorate General for the Development and Protection of Forests and Rural Environment (Ministry for the Environment, Energy and Climate Change), where they are inserted/maintained into an electronic database for all four areas and also uploaded on the Project website.



Field work
EKBY Photo Archive/G. Poulis & V. Chrysopolitou

Autumn landscape in Rodopi, NE Greece
EKBY Photo Archive/L. Logothetis