ADAPTATION OF FOREST MANAGEMENT TO CLIMATE CHANGE IN GREECE: APPLICATION AT FOUR PILOT SITES

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ABSTRACT

Forests are expected to be affected by climate change; consequently, adaptation of forest management to climate change is considered necessary in order to enable the conservation of healthy, productive forests. In the framework of the EU LIFE+ AdaptFor project (www.life-adaptfor.gr), an effort was made to assess vulnerability of four selected Greek forest ecosystems, in terms of forest health and vegetation changes, under the effects of climate change. Following the assessment of the occurring phenomena at these sites (i.e. dieback of Scots pine and Greek fir, intrusion of conifers into broadleaved forests), measures for the adaptation of forest management practices have been designed. Consultation with the competent Forest Services has taken place in order to include also feasibility aspects such as applicability in terms of cost, needs and demands of local population and of wood market. Mostly no- or low-regret adaptation options have been considered, aiming at the reduction of forest ecosystems' vulnerability and the enhancement of their resilience to climate change. The measures include the adaptation of silvicultural techniques (changes in the rotation period, adoption of positive selection, favour of mixed species stands, sanitary logging), but also monitoring and awareness raising activities (adaptive management approach).

Keywords: Forests, climate change, adaptation, management measures

INTRODUCTION

Forests are expected to be affected by climate change; new assemblages of species, shifts in the geographic distribution of forest vegetation and further intensification of infestations by destructive pathogens (e.g. insects and fungi) are expected to occur [1, 2, 3, 4].

The Mediterranean region is not only a biodiversity hotspot [5], it has also been identified as a climatic change hotspot [6]. Drought and extreme forest fire risks are the largest threats especially under water-limited conditions. In addition, forest stands will be weakened by the unfavourable environment which will increase biotic risks. In this context, drought will probably be the main factor driving pest outbreaks in the Mediterranean zone [7]. Moreover, the future presence of a species is likely to be determined by the complex balance of temperature change, water stress and the species-specific capacities [8]. Natural resource conditions are very different in large parts of Southern Europe (compared to resource conditions in Northern Europe), as many forests are located on sites having low potential for environmentally sustainable wood production due to a combination of limiting factors (low site fertility, terrain steepness, high soil erosion risk). However, at the Mediterranean region, social and environmental forest ecosystem services are considered to be far more important (e.g. biodiversity conservation, watershed protection, carbon sequestration, landscape beauty and recreation) [9]. Greece, as part of the Southern Europe and the Mediterranean Basin, is projected to be among the most vulnerable countries to climate change and in need of adaptation measures, according to the 2007 EC Green Paper on adaptation to climate change [10]. It is therefore quite urgent to adapt forest management in the changing climate.

Whilst trees, in much of the earth's forests, will have to adapt to climate change without human intervention, many forested areas can be managed to minimize the undesirable effects of projected increases in tree mortality [11]. The same stands for forest ecosystems; they will eventually adapt autonomously, however their importance to society means that we may wish to influence the direction and timing of this adaptation at some locations [12].

Adaptation planning in the forest sector is important for three main reasons: a) climate change is already occurring in some regions where forest-based communities and forest ecosystems are vulnerable, b) even with aggressive measures to control greenhouse gas emissions, current concentrations of greenhouse gases in the atmosphere commit the earth to continued climate change and c) proactive approaches to adaptation are more likely to avoid or reduce negative impacts of climate change than reactive responses [13, 14, 15]. Further to the above, forest adaptive management is needed to enable us to plan for and manage healthy, productive forests aiming at additional carbon storage in the forest ecosystems combined with sustainable provision of forest goods and services.

Adaptation to climate change refers to adjustments in ecological, social and economic systems in response to the effects of changes in climate. Thus, an effective adaptation policy must be responsive to a wide variety of economic, social, political and environmental circumstances. As discussed by Spittlehouse [16], Dale *et al.* [17], Holling [18] and Smit & Pilifosova [19], adaptation requires us to: a) establish objectives for the future forests under climate change, b) increase awareness and education within the forestry community about adaptation to climate change, c) determine the vulnerability of forest ecosystems, forest communities and society, d) develop present and future cost-effective adaptive actions, e) manage the forest to reduce vulnerability and enhance recovery, f) monitor to determine the state of the forest and identify when critical thresholds are reached and g) manage to reduce the impact when it occurs, speed recovery and reduce vulnerability to further climate change [12].

However, adaptive actions, if applied unwisely or without a good understanding of the biophysical implications, could exacerbate the effects of climate change [20]. On the other hand, forecasting exact impacts is difficult because of our limited knowledge on the vulnerability of ecosystems and species, and because of the poor spatial and temporal resolution of the future climate. However, according to Fussel [21], vulnerability-based assessments can produce useful results even in the absence of reliable impact projections (e.g. by identifying no or low -regret options that are robust against a wide range of plausible climate developments). Besides, as Milad *et al.* [22] state, no-regret-strategies are thought to be beneficial under various future climate conditions.

In the framework of the project EU LIFE+ AdaptFor (www.life-adaptfor.gr), an effort was made to understand the ecological responses and vulnerability of four selected Greek forest ecosystems, in terms of forest health and vegetation changes, under the effects of climate change [23]. Following the diagnosis of the causes and the assessment of the occurring phenomena (i.e. dieback of Scots pine and Greek fir, intrusion of conifers into broadleaved forests), measures to adapt forest management practices in these four ecosystems have been designed. These measures will be finally incorporated in the Forest Management Plans of the four study areas.

METHODOLOGY

Study areas and observed phenomena

In order to demonstrate the approach of adapting forest management to climate change, four pilot sites, distributed throughout Greece, have been selected (Fig. 1). In these sites, changes in vegetation attributed to climate change, have been observed. All four sites are public forest areas and, consequently, managed by State (competent forest services). It is worth mentioning that all four areas overlap with Natura 2000 Network sites. A brief description of the areas, as well as of the occurring phenomena is provided in Table 1 [23].

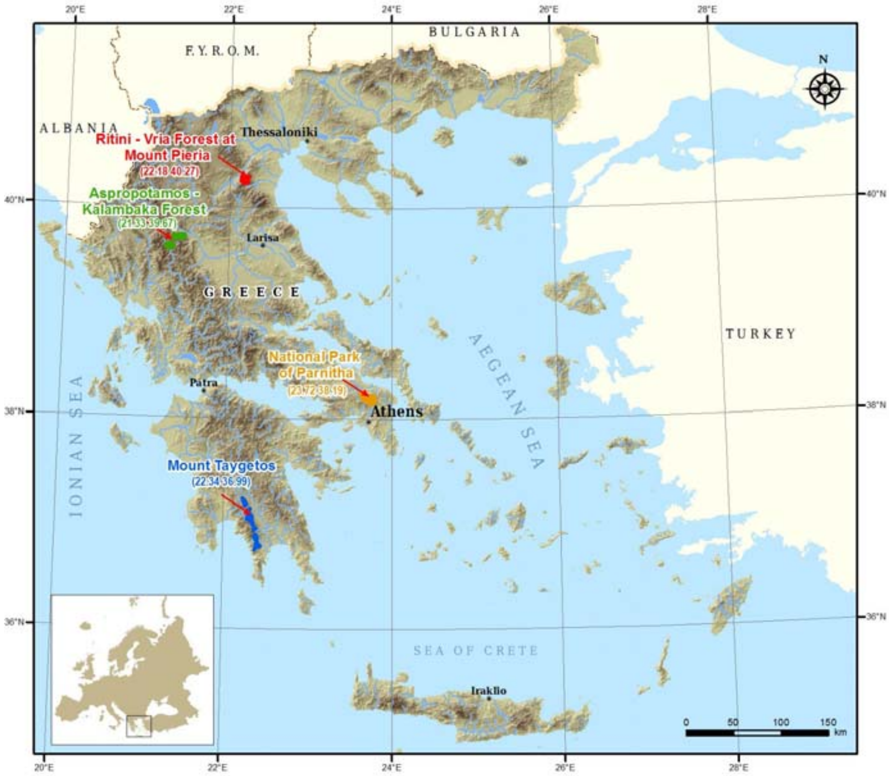

Figure 1. General location of the four selected forest ecosystems in Greece.

Method

Adaptation to climate change can be reactive or proactive and involves a broad range of measures directed at reducing vulnerability to climatic stimuli (changes in means, variability and extremes). Recommendations for adaptation are also determined by their synergy with other policy objectives [21]. In the framework of this study, apart from socio-economic issues related to logging activities, forest biodiversity conservation was taken into consideration. This stems from the fact that the areas are part of Natura 2000 Network and they are natural forests, extensively managed, using pro-silva principles. The design of adaptation and management measures was based on the adaptation process described by Robledo & Forner [24]. The EU guidelines on dealing with the impact of climate change on the management of Natura 2000 Network [25] have been taken into account.

Process followed: Based on the vulnerability assessment, conducted earlier in the project, the specific forest management objectives for each study area have been set. For the achievement of these aims, adaptation measures (short-, medium and long-term as well as supplementary measures), mainly from a scientific point of view, have been proposed by the project team to the competent Forest Services. These measures were subjected to a) open-access, public consultation at the project website and b) extensive consultation with the competent Forest Services (central and local), including the holding of a consultation meeting in which all stakeholders, forest managers and experts participated. All comments received have been evaluated and incorporated into the measures. Comments from the local Forest Services mostly reflected on local conditions, aspirations of local communities, considerations of feasibility in terms of cost, needs and demands of local population and of wood market. Furthermore, since management is an adaptive process itself, aspects of monitoring and re-evaluation of measures have been introduced. As a next step within the project, the measures are going to be specified on the stand level (smallest unit of forest division / unit of silvicultural treatments), and will be incorporated in the Forest Management Plans of the four study areas. Moreover, the experience gained at local level in these four pilot areas will be used to deliver national guidelines targeted to all forest services, for widespread application.

Table 1. Study areas and observed phenomena.

Study area	Forest Type	Occurring Phenomena
Ritini–Vria Forest	Scots pine (*Pinus sylvestris*) in pure stands with an understorey of low shrubs	The extensive dieback of Scots pine observed in this area over the last 30 years seem to be due to the combined action of the primary pathogenic fungus *Peridermium pini* and of bark beetles. The available evidence supports the original hypothesis that changes in climatic parameters over the years have considerably co-acted in this direction.
Aspropotamos–Kalambaka Forest	Mixed forest 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*)	Over the last decades, coniferous forests have intruded lower and into surface areas where broadleaved species normally prevail (700-1000 m a.s.l.). As a consequence, fir extends beyond its lower thermal tolerance limits, becoming vulnerable to insects' outbreaks. It was assumed that inappropriate management applied in the region for many years (clear cuts, coppicing) 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 niches.
National Park of Parnitha	Greek fir (*Abies cephalonica*) in pure or mixed stands with Aleppo pine (*Pinus halepensis*), juniper (*Juniperus* sp.), Kermes oak (*Quercus coccifera*) and broadleaved shrubs	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 climatic 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 climatic conditions, have favoured the expansion of harmful bark beetles.
Mount Taygetos	Greek fir (*A. cephalonica*) in pure or mixed stands with Black pine (*Pinus nigra*), juniper (*Juniperus* sp.) and broadleaved shrubs	The 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.

RESULTS

The overall objective set is to halt further progression of the occurring phenomena regarding vegetation changes attributed to climate change at the four study areas. More specifically, the *Forest Management Objectives* proposed per study area, are:

Ritini–Vria Forest at Mount Pieria: The forest management objective is the conservation of Scots pine forest through prevention of tree dieback. Further, the conservation of the species subpopulations (genetic diversity) is considered of significant importance, as the region is the southernmost limit of Scots pine in Europe.

Aspropotamos–Kalambaka Forest: The overall objective of forest management is the halting of conifer species intrusion into stands where broadleaved species normally prevail. Specifically, at medium and poor quality sites, where fir individuals extend beyond their lower thermal tolerance limits, and consequently become vulnerable to insects' attacks, rehabilitation of the mixed oak forest and of the chestnut forest is proposed. However, at specific good quality sites within the area, fir stands should be favoured.

National Park of Parnitha: The overall objective of forest management is the protection of ecosystem functions against climate change driven disturbances. It should be noted that, in this particular area, forest management is focused on the protection of biotic (conservation of biodiversity) and abiotic factors (improvement of soil conditions, water economy) and not on wood production. Specifically, at good quality sites the conservation of Greek fir is promoted. On the contrary, at degraded sites, where fir lies outside its ecological tolerance limits, the aim is its replacement by other species, more adaptable to marginal conditions.

Mount Taygetos: The forest management objective is the protection of Greek fir against bark beetle and other insect outbreaks. Specifically, the favouring of fir stands (both *A. cephalonica* and *A. borisii regis*) under single-selection silvicultural form is proposed, as this structure creates a forest with high wood stocks, stable equilibrium and greater sequestration and storage capacity of CO_2. The conservation of Greek fir genetic diversity is considered of significant importance, as the region is the southernmost limit of the species.

For the achievement of the above mentioned forest management objectives, the following concrete adaptation measures have been proposed (Table 2). These measures are going to be implemented at approximately 16,000 ha throughout Greece. In particular, the revision of the Forest Management Plans regards ~1,500 ha at Ritini–Vria Forest, ~ 2,500 ha at Aspropotamos–Kalambaka Forest, ~ 4,000 ha at the National Park of Parnitha and ~ 8,000 ha at Mount Taygetos.

Table 2. Forest adaptation measures, proposed for the four selected forest ecosystems.

Study area	Management objective	Measure	Detailed Description
Ritini–Vria Forest at Mount Pieria	Conservation of Scots pine forest	Immediate logging of infected trees (sanitary logging)	Logging of Scots pine trees, infected by bark beetles or by the fungus *P. pini*. Preservation of older trees in stands (5-10 trees/ha) is strongly recommended for the conservation of biodiversity.
		Establishment of pheromone trap network	Suitable attractant substances (during the appropriate season) are used to attract and trap harmful insects (mass depopulation). Alternatively, the conversion of infected trees to tree traps is recommended.
		Enhancement of regeneration (either natural regeneration or by seeding/planting)	Regeneration should focus on logged (due to increased mortality rate) stands, on remaining stands with insufficient regeneration, as also on large areas covered by dense herbaceous vegetation. Fencing of surface areas under regeneration processes (~ 5-10 ha/year) is required as the area is intensively grazed.
		Favouring of mixed stands	Mixed stands comprising of Scots pine with fir and beech should be favoured in the area, especially at sites where the infectious potential (caused by the fungus and bark beetles) is very high.
	Conservation of Scots pine genetic diversity	Preservation of dominant species subpopulations in the area	The area is the southernmost distribution limit of Scots pine in Europe and thus its conservation is considered of major importance.
Aspropotamos–Kalambaka Forest	Rehabilitation of mixed oak forest and chestnut forest at medium / poor quality sites	Immediate logging of infected trees (sanitary logging)	Removal of fir (invasive species) to prevent further bark beetle outbreaks. In this way, competition between fir and oak is reduced and deciduous oak forests are enhanced, providing multiple benefits to the forest (retention of water etc.).
		Favouring of mixed stands	Mixed stands comprising 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	Selective inversion thinning should be applied instead, because a prolonged lack of harvesting activities may increase susceptibility to disturbances (e.g. forest fire).
		Extension of rotation period	An extension of the rotation period from 30 to 120-150 years for oak and chestnut forests is required in order for the management aim to be achieved.
		Application of selective logging and thinning	Selective thinning should be repeated every 8-10 years and its application should be limited only to the overstorey. Conservation and enhancement of the under and middle floor (consisting of species that are known to improve soil conditions), increases the ecosystem's biodiversity and increases soil productivity. Besides, restoration of the natural vegetation diversity on the upper floor of the forest or the stand, usually provokes the gradual restoration of the middle floor and under floor.
	Favouring of fir stands at good quality sites	Application of selective logging and thinning	Favouring of fir stands with gradual removal of the Turkey oak overstorey is recommended. Specifically, the creation of an uneven-aged selective forest using silvicultural treatments (through positive selection) is proposed.

Study area	Management objective	Measure	Detailed Description
National Park of Parnitha	Conservation of Greek fir at good quality sites	Immediate logging of infected trees (sanitary logging)	Logging of fir trees that are infected by bark beetles or by mistletoe (*Viscum album*) or exhibit discrepancies and errors (in terms of morphology and physiology). The latter are at greater risk of necrosis due to climate change, compared to healthy trees.
		Establishment of pheromone trap network	Suitable attractant substances (during the appropriate season) are used to attract and trap harmful insects (mass depopulation). Alternatively, the conversion of infected trees to tree traps is recommended.
		Enhancement of regeneration (either natural regeneration or by seeding/planting)	Planting of four-year old seedlings has already been applied in the area, with great success (restoration after 2007 forest fire). The 2nd year after planting, survival rose up to 70-80.
		Application of selective logging and thinning	Intensification of thinning at this area, aiming at water balance improvement and at drought effects' mitigation, is required.
	Replacement of Greek fir by other species at degraded soils	Changes in species composition	Where the Greek fir lies outside its ecological tolerance limits, it should be replaced by Prickly juniper (*Juniperus oxycedrus*) or by Downy oak (*Quercus pubescens*). Both species, native to the area, can cope with adverse climatic and soil conditions. Oak species, in particular, can gradually create a forest capable of performing ecological functions necessary for the conservation of biodiversity and of providing services to humans. Further to the above, oak forests may enhance the regeneration of fir species.
Mount Taygetos	Conservation of fir forests (*A. cephalonica* and *A. borisii regis*)	Immediate logging of infected trees (sanitary logging)	In the southern part of the area, where the forest is of low quality (poor soil conditions and grazing), the removal of dead or infected Greek fir individuals is expected to improve the forest stands' health and to reduce competition at the overstorey.
		Establishment of pheromone trap network	Suitable attractant substances (during the appropriate season) are used to attract and trap harmful insects (mass depopulation). Alternatively, the conversion of infected trees to tree traps is recommended.
		Enhancement of regeneration (either natural regeneration or by seeding/planting)	Following logging activities, gaps in the forest should be filled either by favouring natural regeneration or by planting four-year old seedlings.
		Favouring of mixed stands	Mixed stands comprising of Greek fir and Black pine or Greek fir, Black pine and chestnut (depending on the location), may be favoured. In particular, Black pine plays an important ecological role, acting in some cases 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 logging and thinning	Favouring of fir stands (both *A. cephalonica* and *A. borisii regis*) under single-selection silvicultural form is required to increase trees' diameter up to 70-80 cm. However, in some selected locations, the annual harvest should increase from 9-10% to 20-22% in every rotation period (encouragement of Greek fir regeneration and greater adaptation to emerging climate change, as young trees are more adaptable).
	Conservation of Greek fir genetic diversity	Preservation of dominant species genetic diversity in the area	The area is the southernmost distribution limit of Greek fir in Greece and thus its conservation is considered of major importance.

Study area	Management objective	Measure	Detailed Description
ALL AREAS	Protection of forests from other biotic and abiotic factors	Limitation of grazing by wild and domestic animals	Grazing pressure, which has detrimental effects on the regeneration of the forest stands, should be moderated through the installation of chain-link fences (e.g. in the case of the Ritini-Vria Scots pine forest) or the control of wild animals (e.g. in the case of the Parnitha Greek fir forest).
		Preventive and repressive measures against forest fires	All suitable preventive and repressive measures (e.g. fuelbreaks) should be implemented as both the frequency and the intensity of forest fires are expected to increase due to climate change.
		Gradual afforestation of forest roads	The afforestation of decommissioned forest roads is expected to reduce fragmentation of forest vegetation.
		Protection of soil resources during the application of silvicultural treatments	The protection of the soil resources is highly prioritized in the mountainous Greek forests. The proposed measures include the selection of the appropriate machinery and the training of logging crews towards this direction.
	Research and awareness	Establishment of permanent monitoring programme	Sixteen permanent plots (four plots/area) have been established for the monitoring of stand structure and soil attributes. The aim is to evaluate climate change impacts, monitor the course of the occurring phenomena and test the success of the applied measures. Special emphasis is given on monitoring of the dominant vegetation species and vegetation units/structures at each area, as these are considered to be indicators of the ecological conditions' alterations under the effects of climate change. Further to the above, the monitoring network includes one telemetric meteorological station for the monitoring of climatic parameters (temperature, precipitation etc.) at each area.
		Awareness raising	Actions include training seminars to the local Forest Services personnel and awareness raising of relevant stakeholders and of the general public.

DISCUSSION

The adaptation of forest management to climate change is promoted through the application of sustainable silvicultural practices, aiming at the enhancement of productivity and environmental services but, at the same time, 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, the increase in connectivity and the continuous monitoring of forest health [26]. These adaptation measures will eventually render ecosystems less vulnerable and will also contribute to the mitigation of climate change induced impacts (by increasing sequestration and storage capacity of CO_2).

The proposed measures shown in Table 2 above can be divided into the following categories: a) *short-term adaptation measures* to be implemented immediately for controlling the occurring phenomena, b) *medium and long-term adaptation measures* for the enhancement of forest ecosystems under the effects of climate change and c) *supplementary measures* required for the success of adaptation measures and for the protection of forests from biotic and abiotic factors. In general, mostly no- or low-regret options focused on maintaining and increasing the resilience of the forest ecosystems in question were adopted.

Short-term adaptation measures

Sanitary logging (removal and disposal of infected treed) is implemented at areas suffering from epidemic bark beetle or fungi outbreaks, in order to reduce the infectious potential and avoid similar incidents over the following years. In some cases, especially during hot and dry periods, even the removal of trees with disturbed physiology is considered necessary for the protection of forest ecosystems. In order to maintain the standing stock and thus ensure sustainability, the harvested wood volume is deducted from the estimated annual logging volume. During logging activities, creation of irregular stand structure and gaps in the forest should be avoided, as sanitary logging can even cause alterations in stand structural complexity, community composition and species populations [27]. Complementary, the *establishment of pheromone traps* is proposed to protect study areas from further insects' outbreaks.

Medium and long-term adaptation measures

Regarding *regeneration encouragement*, Lindner [9] states that the maintenance or improvement of the genetic adaptive capacity of populations and species is important to facilitate natural adaptation to climate change, especially in the long-term. Seeds should come from healthy, neighboring individuals in order to safeguard the local genetic diversity of the subpopulations and to avoid changes in the spatial distribution patterns of subpopulations within each area [28, 29, 30]. Soil conditions are considered a key factor for the success of regeneration. In the case surfaces are covered by a dense layer of vegetation, soil scarification (up to ~10 cm depth) or removal of the forest floor, is required [31].

The *favouring of mixed stands*, in terms of both compositional and structural diversity, can be achieved either naturally (through the use of silvicultural techniques) or artificially (plantings to create a mosaic of mixed stands), where of course the gravimetric and microenvironmental conditions are suitable. The establishment and maintenance of forests with diverse species and age classes may enhance the stability of forest ecosystems, improving its adaptive capacity and increasing tree resilience to mortality in response to pathogen activity and climate change [17, 32, 33, 34, 11]. Furthermore, the mixing of species is considered to be a positive management measure as it increases forests' drought resistance and reduces fire risk [7]. Oak species, in particular, can gradually create a forest that supports ecological functions necessary for the conservation of biodiversity and provides services to humans. Also, oak forests may enhance the regeneration of fir species [29].

Cessation of clear cuts to broadleaved forests is considered to be a necessary first step for the inversion and subsequent conservation of these forests. Clear cuts, when applied in a certain area for many years, usually result is soil degradation as a large amount of nutrients is being permanently removed from the ecosystem. Further, clearcutting often contributes to the reduction in soil water-holding capacity and the increase of erosion procedures [35]. This adverse effect is even more intense at mountainous forests, where the inclinations are high. Clear cuts are considered to be a strong form of disruption, retaining vegetation at an early development stage and significantly reducing the mature individuals who can act as seeders. Furthermore, clear cuts can set distribution restrictions of species which cannot stand repeated disturbances or require more favourable conditions for their establishment (e.g. soil rich in nutrients, shady environment, etc.). On the other hand, susceptibility to disturbances may also increase due to a prolonged lack of harvesting activities. Biotic and abiotic disturbances occurring in neglected coppice forests are, at least partially, an effect of the lack of management which causes increased fuel wood accumulation [7]. Complementary to the above, the *extension of rotation period* generally protects soil productivity and further reduces the risk of erosion and soil degradation. Noss [36] advises against reduced rotation periods on the basis that critical soil nutrients may be depleted. An extension of the rotation period leads to greater biomass concentration and consequently higher sequestration rates and greater storage capacity of CO_2, for economic and ecological reasons [37, 33, 38]. In addition, the production of more valuable timber (larger in size) is achieved. In the Mediterranean region, in particular, an intensified management regime might have detrimental effects in erosion prone environments, where an increase of rotation length, especially in coppices, is recommended. However, for stands predisposed to e.g. storm damage or bark beetle attacks, a shortening of rotation periods could significantly decrease susceptibilities [7].

The *application of selective logging and thinning* and further modifications in their frequency or intensity is strongly recommended for a variety of reasons. These silvicutural treatments reduce both inter- and intraspecific competition for water, light and nutrients [39] and thus render species less vulnerable to the attacks of pathogens. As a result, a higher growing stock is maintained, increasing the trees' diameter and thus achieving greater sequestration and storage capacity of CO_2. Moreover, water balance within the forest ecosystem is restored and negative impacts from droughts and forest fire are mitigated [40].

The *preservation of the dominant species genetic diversity* can contribute to the evaluation of possible future impacts on forests related to any disturbance (e.g. forest fire) and subsequently to the implementation of restoration actions in cases when natural recovery of the forest ecosystem is deemed impossible or very slow. Preservation can be achieved either by selecting and preserving (e.g. seed bank) propagating material representative of the species' genetic diversity or by establishing seed orchards, using the above mentioned material. Alternatively, natural stands with optimal phenotypes can be selected for the collection of seeds.

Supplementary measures

Supplementary measures aim mainly at the limitation of vegetation fragmentation and at the protection of abiotic resources. The *limitation of grazing* both by wild and domestic animals is considered necessary for the protection of regeneration and soil resources (compaction of soil). Grazing has a negative impact on the understorey as well as on the regeneration of species, as it is considered to be an important regulatory factor especially following disturbances, such as forest fire. Thus, fencing of areas that are under regeneration process, adjustment and rationalization of grazing by domestic animals or control of wild animals' populations are needed. *Protection of soil resources* during the implementation of management measures should be considered. Management methods that destroy the forest floor should be avoided, particularly in cases where the soil exhibits a low filtration rate. Also, *preventive and repressive measures against forest fires* should be taken as many species at the study areas (e.g. fir) are unadjusted to fire and their regeneration after fire is considered very difficult. In order to limit vegetation fragmentation, the *gradual afforestation of forest roads* no longer necessary for forest management and protection is proposed. Another option would be the connection of forest stands through biological corridors. Reducing forest fragmentation through afforestation and by establishing connecting corridors between densely forested regions contributes to increasing biodiversity and thus enhances natural adaptive capacity [9, 39, 41].

Research is needed to limit uncertainties regarding the impacts of climate change to forest ecosystems. The *establishment of a permanent monitoring programme* offers the basis for adaptive management [42, 43, 44, 38]. A robust monitoring system is important to assess climate change impacts (including dieback and pest dynamics) and the reaction of forest ecosystems to the adaptive management strategies [45]. *Awareness raising* and training of stakeholder groups (forest managers, etc.) is considered to be an important element, as adaptation strategies will be more successful if they are identified and developed by local actors. In this way, they are more likely to be consistent with local priorities, goals, norms, and institutions [46, 47]. Given that deficits in motivation may considerably reduce adaptation results, bottom-up approaches, which include the relevant stakeholders, are vital [48]. Also, the general public has to be properly motivated, in terms of educational training and participatory actions to protect the natural ecosystems, especially in areas that receive large amounts of visitors i.e. National Park of Parnitha.

Conclusively, the ultimate goal was to interlink climate change considerations with biodiversity conservation priorities and socio-economic aspects and mainstream all the above into forest management planning. The challenge in using an adaptive management approach lies in finding the correct balance between the need to gain knowledge for improving management in the future and to achieve the best outcomes based on current knowledge [49]. Adaptive forest management is characterised by continual evaluation and, if necessary, adjustment of management objectives [50, 51, 52, 53]. As it is unlikely that uncertainties will be totally reduced in the future [54], knowledge gaps are to be explicitly integrated in management.

The current study puts science, guidelines and prescriptions for management into practice with the hope to bridge the gap between science and policy, in light of the changing climate. Co-operation of scientists, decision makers and stakeholders is expected to lead to the development and evaluation of adaptation strategies through a participative process [7].

ACKNOWLEDGEMENTS

The current study was conducted in the framework of the project EU LIFE+ ENVIRONMENT POLICY AND GOVERNANCE, LIFE08 ENV/GR/000554, entitled AdaptFor "Adaptation of forest management to climate change in Greece" which is implemented by the Goulandris Natural History Museum/Greek Biotope-Wetland Centre (EKBY) in cooperation with the General Directorate for the Development and Protection of Forests and Natural Environment/Ministry of Environment, Energy and Climate Change (GDfDPFNE/MinEECC). The project duration is 5 years and its budget amounts to EUR 1,719,112. With the contribution of the LIFE financial instrument of the European Community.

REFERENCES

[1] R.J. Hebda, Impact of climate change on biogeoclimatic zones of British Columbia and Yukon. In: Taylor E, Taylor B (eds) Responding to global climate change in British Columbia and Yukon. Environnent Canada, Vancouver, 1997, pp. 13-1–13-15.

[2] M.U.F. Kirschbaum, Forest growth and species distribution in a changing climate. Tree Physiol., 20 (2000) 309–322.

[3] A.J. Hansen, R.P. Neilson, V.H. Dale, C.H. Flather, L.R. Iverson, D.J. Currie, S. Shafer, R. Cook and P.J. Bartlein, Global change in forests: response of species, communities, and biomes. Bioscience, 51 (2001) 765–779.

[4] J.A. Logan, J. Regniere and J.A. Powell, Assessing the impact of global warming on forest pest dynamics. Front. Ecol. Environ., 1(3) (2003) 130–137.

[5] E.C. Underwood, J.H. Viers, K.R. Klausmeyer, R.L. Cox and M.R. Shaw, Threats and biodiversity in the Mediterranean biome. Diversity and Distributions, 15 (2009) 188–197.

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

[7] M. Lindner, J. Garcia-Gonzalo, M. Kolström, T. Green, R. Reguera, M. Maroschek, R. Seidl, M.J. Lexer, S. Netherer, A. Schopf, A. Kremer, S. Delzon, A. Barbati, M. Marchetti and P. Corona, Impacts of Climate Change on European Forests and Options for Adaptation. Report for DG Agriculture. European Forest Institute, Joensuu, Finland, 2008.

[8] J. Penũelas, J.M. Hunt, R. Ogaya and A.S. Jump, Twentieth century changes of tree-ring delta ^{13}C at the southern range-edge of *Fagus sylvatica*: increasing water-use efficiency does not avoid the growth decline induced by warming at low altitudes. Glob. Change Biol., 14 (2008) 1076–1088.

[9] M. Lindner, 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, Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. For. Ecol. Manag., 259 (2010) 698-709.

[10] CEC (Commission of the European Communities), Adapting to climate change in Europe: options for EU action. Green Paper, Brussels, 2007.

[11] R.N. Sturrocka, S.J. Frankelb, A.V. Brownc, P.E. Hennond, J.T. Kliejunasb, K.J. Lewise, J.J. Worrallf and A.J. Woods. Climate change and forest diseases. Plant Pathol., 60 (2011) 133–149.

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

[13] W.E. Easterling, W.H. Hurd and J.B. Smith, Coping with global climate change: the role of adaptation in the United States. Pew Centre on Global Climate Change, Arlington, Virginia, USA. 2004.

[14] J. Ford, T. Pearce, B. Smit, J. Wandel, M. Allurut, K. Shappa, H. Ittusujurat and K. Qrunnut, Reducing vulnerability to climate change in the Arctic: the case of Nunavut, Canada. Arctic, 60(2) (2006) 150–166.

[15] W. Hare and M. Meinshausen, How much warming are we committed to and how much can be avoided? Clim. Chang., 75(1–2) (2006) 111–149.

[16] D.L. Spittlehouse, Forest management and climate change. In: Taylor E, Taylor B (eds). Responding to global climate change in British Columbia and Yukon. Environment Canada, Vancouver, 1997, pp. 24-1–24-8.

[17] V.H. Dale, L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks and B.M. Wotton, Climate change and forest

disturbances. Bioscience 51 (2001) 723–734.

[18] C.S. Holling, Understanding the complexity of economic, ecological, and social systems. Ecosystems, 4 (2001) 390–405.

[19] B. Smit and O. Pilifosova, Adaptation to climate change in the context of sustainable development and equity. In: J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White (eds) Climate change 2001: impacts, adaptation, and vulnerability. Intergovernmental Panel on Climate Change, Cambridge University, New York, 2001, pp 876–912.

[20] P.N. Duinker, Climate change and forest management, policy and land use. Land Use Policy, 7 (1990) 124–137.

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

[22] M. Milad, H. Schaich and W.Konold, How is adaptation to climate change reflected in current practice of forest management and conservation? A case study from Germany. Biodivers. Conserv., 22 (2013) 1181–1202.

[23] V. Chrysopolitou, N. Avtzis, S. Diamandis, D. Kemitzoglou, D. Papadimos, C. Perlerou, V. Tsiaoussi and S. Dafis, Studies on forest health and vegetation changes in Greece under the effects of climate changes. Biodivers. Conserv., 22(5) (2013) 1133-1150.

[24] C. Robledo and C. Forner, Adaptation of Forest Ecosystems and the Forest Sector to Climate Change. Forests and Climate Change Working Paper 2. Jointly produced by FAO and the Swiss Agency for Development and Cooperation (SADC) 2005.

[25] European Union, 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.

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

[27] D.B. Lindenmayer and R.F. Noss, Salvage logging, ecosystem processes, and biodiversity conservation. Conserv. Biol., 20(4) (2006) 949-58.

[28] G. Karetsos, First thoughts and proposals for the restoration of the burnt fir forest of the Parnitha National Park (in Greek), In: Proceedings of the Geotechnical Chamber Committee for the restoration of Parnitha, Thessaloniki, 2008, pp. 9-15.

[29] G. Karetsos and E. Daskalakou, The proposals of the Forest Ecology and Forest Management Laboratories of the Institute of Mediterrranean Forest Ecosystems for the restoration of the Parnitha National Park (in Greek), In: Proceedings of the Geotechnical Chamber Committee for the restoration of Parnitha, Thessaloniki, 2008, pp. 27-28.

[30] Ch. Kostoudi, Genetic diversity of Greek fir (*Abies cephalonica*) in Parnitha. Thesis, Department of Forestry and Management of Environment and Natural Resources, Postgraduate Studies Program, Orestiada, 2012.

[31] E. Stamatopoulos, The regeneration of Greek fir in the Parnitha National Park (in Greek), Doctoral Thesis, Department of Forestry and Natural Environment, Aristotle University of Thessaloniki, 1995.

[32] T. Elmqvist, C. Folke, M. Nystrom, G. Peterson, J. Bengtsson, B. Walker and J. Norberg, Response diversity, ecosystem change, and resilience. Front. Ecol. Environ., 1 (2003) 488–494.

[33] A.M. Evans and R. Perschel, A review of forestry mitigation and adaptation strategies in the Northeast U.S. Clim. Chang., 96 (2009) 167–183.

[34] K.J. Puettmann, K.D. Coates and C.C. Messier, A Critique of Silviculture: Managing for Complexity. Island Press, Washington, DC, 2009.

[35] W. Schönenberger and P. Brang, Silviculture in Mountain Forests, In: J. Burley, J. Evans and J.A. Youngquist. Encyclopedia of Forest Sciences, Elsevier, 2004.

[36] R.F. Noss, Beyond Kyoto: forest management in a time of rapid climate change. Conserv. Biol., 15(3) (2001) 578–590.

[37] L.C. Brett, Desired vegetation condition and restoration goals in a changing climate: a forest, management challenge. US For. Serv. T R PNW 733. 2008, pp. 49–56.

[38] P.J. Burgess, A.J. Moffat and R.B. Matthews, Assessing climate change causes, risks and opportunities in forestry. Outlook. Agr., 39 (4, Sp. Iss. SI) (2010) 263–268.

[39] H. Spiecker, Silvicultural management in maintaining biodiversity and resistance of forests in Europe—Temperate zone. J. Environ. Manag., 67 (2003) 55-65.

[40] S. Sabaté, C.A. Gracia and A. Sánchez, Likely effects of climate change on growth of *Quercus ilex*, *Pinus halepensis*, *Pinus pinaster*, *Pinus sylvestris* and *Fagus sylvatica* forests in the Mediterranean region. For. Ecol. Manag., 162 (2002) 23-37.

[41] O. Honnay, K. Verheyen, J. Butaye, H. Jacquemyn, B. Bossuyt and M. Hermy, Possible effects of habitat fragmentation and climate change on the range of forest plant species. Ecol. Lett., 5 (2002) 525-530.

[42] D. Scott and C. Lemieux, Climate change and protected area policy and planning in Canada. Forest Chron., 81(5) (2005) 696–703.

[43] D. Coenen, I. Porzecanski and T.L. Crisman, Future directions in conservation and development: incorporating the reality of climate change. Biodiversity, 9 (3–4) (2008) 106–113.

[44] J. Lawler, T.H. Tear, C. Pyke, R.M. Shaw, P. Gonzalez, P. Kareiva, L. Hansen, L. Hannah, K. Klausmeyer, A. Aldous, C. Bienz and S. Pearsall, Resource management in a changing and uncertain climate. Front. Ecol. Environ., 8(1) (2010) 35–43.

[45] P. Corona, Integration of forest mapping and inventory to support forest management. I. Forest, 3 (2010) 59-64.

[46] J. Newton, C.D. Paci and A. Ogden, Climate change and natural hazards in northern Canada: integrating indigenous perspectives with government policy. Mitig. Adapt. Strat. Gl., 10 (2005) 541–571.

[47] F.S. Chapin, A.L. Lovecraft, E.S. Zavaleta, J. Nelson, M. Robards, G. Kofinas, S. Trainor, G.D. Peterson, H. Huntington and R.L. Naylor, Policy strategies to address sustainability of alaskan boreal forests in response to a directionally changing climate. In: Proceedinds of the National Academy of Sciences Early Edition, 2006, pp. 1–7.

[48] B. Frommer, Climate change and the resilient society: utopia or realistic option for German regions? Nat. Hazards., 58 (2011) 85–101.

[49] C. Allen and G.H. Stankey, Adaptive Environmental Management: A Practitioner's Guide. Springer, 2009.

[50] P. Lasch, M. Lindner, M. Erhard, F. Suckow and A. Wenzel, Regional impact assessment on forest structure and functions under climate change - the Brandenburg case study. For. Ecol. Manag., 162(1) (2002) 73–86.

[51] A. Rigling, P. Brang, H. Bugmann, N. Kräuchi, Th. Wohlgemuth and N.E. Zimmermann, Klimawandel als Prüfstein für die Waldbewirtschaftung (Klimanderung und Waldbewirtschaftung). Schweiz. Z. Forstwes., 159(10) (2008) 316–325.

[52] A. Bolte, C. Ammer, M. Lof, P. Madsen, G.J. Nabuurs, P. Schall, P. Spathelf and J. Rock, Adaptive forest management in central Europe: climate change impacts, strategies and integrative concept. Scand. J. For. Res., 24(6) (2009) 473–482.

[53] J. Lawler, T.H. Tear, C. Pyke, R.M. Shaw, P. Gonzalez, P. Kareiva, L. Hansen, L. Hannah, K. Klausmeyer, A. Aldous, C. Bienz and S. Pearsall, Resource management in a changing and uncertain climate. Front. Ecol. Environ., 8(1) (2010) 35–43.

[54] S.T. Gray, From uncertainty to action: climate change projections and the management of large natural areas. Bioscience, 61(7) (2011) 504–505.