ENVIRONMENTAL RESEARCH
LETTERS

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To cite this article: Jorge Curiel-Esparza *et al* 2015 *Environ. Res. Lett.* **10** 094022

Environmental Research Letters

OPEN ACCESS

RECEIVED
27 April 2015

REVISED
27 August 2015

ACCEPTED FOR PUBLICATION
27 August 2015

PUBLISHED
16 September 2015

LETTER

Integrating climate change criteria in reforestation projects using a hybrid decision-support system

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Keywords: AHP, Delphi, reforestation, climate change, Mediterranean region

Abstract

The selection of appropriate species in a reforestation project has always been a complex decision-making problem in which, due mostly to government policies and other stakeholders, not only economic criteria but also other environmental issues interact. Climate change has not usually been taken into account in traditional reforestation decision-making strategies and management procedures. Moreover, there is a lack of agreement on the percentage of each one of the species in reforestation planning, which is usually calculated in a discretionary way. In this context, an effective multicriteria technique has been developed in order to improve the process of selecting species for reforestation in the Mediterranean region of Spain. A hybrid Delphi-AHP methodology is proposed, which includes a consistency analysis in order to reduce random choices. As a result, this technique provides an optimal percentage distribution of the appropriate species to be used in reforestation planning. The highest values of the weight given for each subcriteria corresponded to FR (fire forest response) and PR (pests and diseases risk), because of the increasing importance of the impact of climate change in the forest. However, CB (conservation of biodiversitiy) was in the third position in line with the aim of reforestation. Therefore, the most suitable species were *Quercus faginea* (19.75%) and *Quercus ilex* (19.35%), which offer a good balance between all the factors affecting the success and viability of reforestation.

1. Introduction

On 24th September 2008, the current Secretary-General of the United Nations stated with reference to the United Nations Collaborative Program on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD) that climate change cannot be mitigated without the proactive management of the world's forests. This, however, will be a complex and challenging feat (Ki-moon 2008). Monitoring the effectiveness of planned interventions is a key factor in developing reforestation projects (Salvini *et al* 2014). Following this line, a new European Union Forest Strategy for forests and the forest-based sector has been proposed (EUCOM 2013), implementing the strategy adopted (EUCON 1999) and related to the EU Forest Action Plan (EUCOM 2006). The EU Forest Strategy (EUCOM 1998) points out the challenges facing the policy and legal framework for forests in the EU as well as the common forest policy objectives for EU Member States. This European strategy emphasizes the importance of the forests' multifunctional role in the development of society. It shows that forests and forestry can successfully provide society with multiple benefits. Thus the European Parliament (EUPAR 2011) considers that Mediterranean forests are highly valued sinks of atmospheric carbon and sources of European diversity and should therefore benefit from enhanced protection. Furthermore, the EU biodiversity strategy to 2020 (EUCOM 2011) encourages Member States to ensure that forestation is carried out in accordance with the pan-European operational level guidelines for sustainable forest management. In order to develop these EU targets and to reduce the alarmingly high rate of global deforestation, reforestation, together with afforestation, forest rehabilitation and other means of rehabilitation, play an important role in EU forest policy.

According to the EU Forest Strategy, European forests serve different purposes such as social (contribution to rural development, recreation), economical (timber, cellulose, packaging, paper, renewable energy), environmental (conservation of biological diversity, action to combat desertification, carbon sequestration which mitigates climate change, protection against soil erosion, avalanche control, regulation and enhancement of streams and rivers) and societal (recreation, employment in rural areas). Guidelines and recommendations from international organizations such as FAO (FAO 2013), IPCC (IPCC 2014a and 2014b), CPF (CPF 2008) and IUNC (IUNC 2004) could also be taken into account. Most of those documents incorporate specific sections for each of the six continents, so a wide range of indicators can be extracted from them according to different environmental conditions worldwide. Hence forest systems are inherently complex and there are several criteria that may be considered in the evaluation of the different species for a reforestation project. Moreover, the specific features of Mediterranean forests highlight the need for achieving a successful reforestation, as the selection of appropriate species is a vital component in a reforestation project, because of the significant long-term implications of such a decision for management costs and the value to the final community. Moreover, the complexity is currently increasing because of the way in which different social groups or stakeholders perceive the relative importance of the criteria involved in the decision-making process (Diaz-Balteiro and Romero 2008, Akiner and Akiner 2010, Hunt *et al* 2014). In view of these difficulties, today's reforestation planning calls for the use of expert systems as a versatile tool for decision support (Orsi *et al* 2011). In this context, the regional forest action plan for Comunitat Valenciana (Spain) forces decision makers to use multicriteria techniques in order to select appropriate species in reforestation planning (PATFOR 2013).

Under Mediterranean climatic conditions, the main problems are drought (Sanchez-Salguero *et al* 2012) and forest fires (Amraoui *et al* 2015), and related to that or as a consequence of them can be mentioned a long time sunlight exposure (Kaya and Kahraman 2011), soil erosion (Ramos and Martinez-Casasnovas 2015) and pest outbreaks (Hódar *et al* 2012). Different criteria might be chosen by the panel of experts, such as ozone concentrations (Paoletti 2005). In fact, in different latitudes may pose a problem just the contrary, the lack of sunlight (Hitsuma *et al* 2015) or waterlogged soils after a flood (Velmurugan *et al* 2015), indeed any other issues such as snow-induced damage on branchs (Kane and Finn 2014), the lack of soil nutrients (Sullivan *et al* 2015) like permafrost affected soils (Dymov *et al* 2015) or the presence of pollutants in soils (Hockmann *et al* 2015). There are other criteria related to the aim of the forestation, such as biodiversity conservation, tourist attractiveness (TA) and wildlife and landscape improvement. They are general enough criteria that can be applied to different aims, such as environmental protection or restoration. However, in the specific case of timber production, different criteria should be taken into account, such as incomes or revenues, log properties such as strengthening or flexure or method of forestation, among others (Denzler *et al* 2015, Hampel *et al* 2015) regarding economic criteria, they are general enough and can be applied to any study case. Nevertheless, other criteria can be added depending the specific features of the forestation project.

This study proposes a decision-support system integrating climate change criteria for optimal reforestation planning using the Delphi Method and Analytical Hierarchy Process (AHP). The methodology is applied to a case study of the Spanish forest in the Mediterranean region. Delphi methodology is used to assess the suitability of various species compatible with the ecological features of the reforesting stand, when considering for instance climatic, physiographical and edaphic factors and potential vegetation. Such species are evaluated according to the purpose of reforestation with reference to several defined criteria proposed by the planning strategies. The task involves determining a ranking of the criteria and their priority using AHP methodology (Saaty 2013, Martin-Utrillas *et al* 2015a). The proposed innovation includes the ecological and socio-economic repercussions of climate change, which are not taken into account in traditional decision-making strategies, in order to reduce the adverse effects of climate change. As a result, the combined Delphi-AHP methodology provides an optimum percentage distribution of the appropriate species to be used in the planning of reforestation incorporating adaptation to climate change.

2. Applied methodology for selecting species

Species able to respond to climate change do so by distributional or phenological shifts, acclimating or adapting (Easterling *et al* 2000, Parmesan 2006, Chen *et al* 2011). Newman *et al* (2011) focuses on the processes by which species respond to climate change, whereas Hannah (2010) offers a more applied perspective. Current researches' (Pettorelli 2012) aim to address the underlying mechanisms of species response and forecast species interactions. Extensive phenological data sets, including those presented in Fitter and Fitterm (2002) and Lenoir *et al* (2008), reveal how the characteristics of species influence the magnitude of phenological shifts. And these shifts may indicate effective acclimation and viability of species. Sexton *et al* (2009) reviews the range limits crucial to species responses to environmental change. Hofmann and Todgham (2010) reviews physiological mechanisms by which organisms may respond to climate change and Gilman *et al* (2010) proposes that identifying the key interactions provides a way to predict how biotic interactions influence responses to climate change. According to this model, DeLucia *et al* (2012) points to the importance of factors such as biotic interactions between plants and insects and Lau and Lennon (2012) provides an example of how the evolution of interacting plant species with rapid life cycles and soil microbial communities may influence responses to environmental changes like drought stress. Finally, Williams *et al* (2008) proposes a framework for assessing the vulnerability of species to climate change, including biotic vulnerability, exposure to climate change, potential evolutionary and acclimatory responses and the potential efficacy of management strategies. As a conclusion, Bucley (2014) highlights the need to integrate accurately forecast species responses in many traditional fields such as physiology, evolution, population and community ecology.

Species suitable for reforestation are determined by using the Delphi technique. Marques *et al* (2013) apply a Delphi survey aimed at identifying empirical guidelines to assist developers and users of decision-support systems for forest management. Experts are given a preliminary list of possibly suitable species according to bioclimatic zone (Gomez-Aparicio *et al* 2011), phytoclimatic versatility (Garcia-Lopez and Allue-Camacho 2008), ecophysiology (Cabrera 2002), physiographical variables (Boucher *et al* 2014) and stand conditions such as soil features, orientation and altitude (Urli *et al* 2014). The best alternatives for the area must be identified, bearing in mind the main goal of reforestation, i.e. biodiversity conservation. Orsi *et al* (2011) performed a Delphi process aimed at defining the key ecological criteria and indicators when considering biodiversity conservation as the main objective of reforestation. At this first stage, a Delphi methodology provides a significant basis for arriving at a consensus.

Delphi methodology is based on expert surveys in several rounds in which the survey results from the previous round are given as feedback on the second and subsequent rounds. The objective of this technique is to obtain the most reliable consensus of opinion from a group of experts (Garson 2013). As a result of this procedure, judgments of a panel of experts are elicited and refined (Meddour-Sahar *et al* 2013). Therefore, Delphi main features are iteration, feedback and anonymity of responses. The group of experts is made up of staff of nature reserves, regional officers, environmental organizations and forestry researchers. They are given a list of species to be evaluated on a numerical scale according to their suitability for the region's natural environment.

Once the appropriate species have been determined, they are compared in pairs with each one of the criteria and translated into numerical values. These criteria and subcriteria represent economical aspects, environmental services and effects of climate change on forest biodiversity that are expected to arise and could not be adequately managed by conventional approaches to conservation, as shown in figure 1. AHP technique is used to evaluate criteria according to the objective of biodiversity conservation of reforestation, dealing not only with traditional economic and environmental aspects (Martin-Utrillas *et al* 2015b), but also with climate change factors. There is a need to provide a method which allows policy-makers and stakeholders to take appropriate measures to adapt to climate change. The proposed decision-support system for selecting species combines a Delphi-AHP model and provides a systematic approach to evaluating multi-criteria and multi-species problems.

The AHP methodology provides a framework within which these selected species can be prioritized while giving a specific weight to the different criteria (Saaty 2008). This method allows the decision maker to arrive at judgments with regard to the species and the criteria according to which the species are evaluated. Moreover, there are non-commensurable criteria that should be considered simultaneously in order to arrive at a more accurate selection (Canto-Perello *et al* 2013, Curiel-Esparza *et al* 2014). The target of this second stage of reforestation planning is a prioritized list of species, a measure of their relative priority and an index denoting the consistency of the decision maker. As shown in figure 1, the AHP process is developed using a three-level hierarchical structure: criteria, sub-criteria and species.

3. Determining criteria and subcriteria for species selection

The criteria and subcriteria have been chosen by the panel of experts taking into account guidelines and recommendations from: the Climate Change Guidelines for Forest Managers (FAO 2013); the Intergovernmental Panel on Climate Change (IPCC 2014a, 2014b); the Ministerial Conferences on the Protection of Forests in Europe (MCPFE 2002, 2007, 2011); the Strategic Framework for Forests and Climate Change proposed by the Collaborative Partnership on Forests (CPF 2008), and from the International Union for Conservation of Nature's Guidelines for Afforestation and Reforestation for Climate Change Mitigation (IUNC 2004). The first criterion relates to the effect on various environmental services (EES) provided by multifunctional forests. The second criterion is connected with the

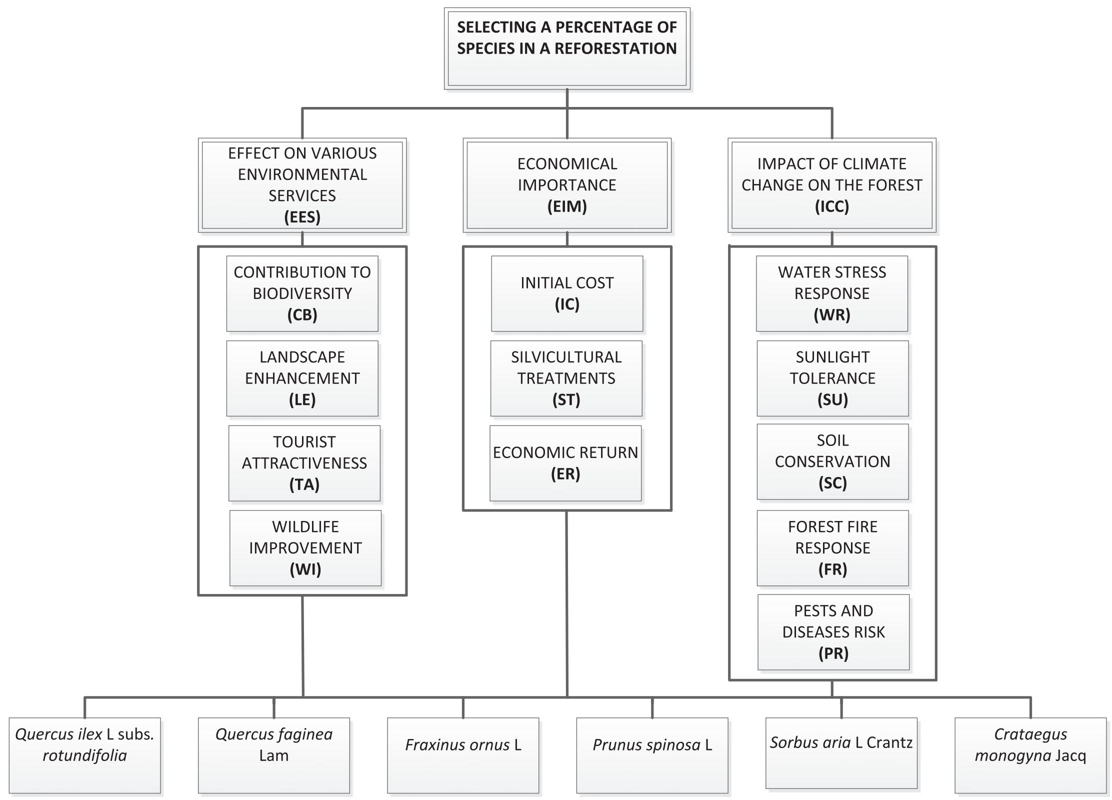

Figure 1. Hierarchy structure including criteria and subcriteria proposed by the panel of experts to determine the combination of species in a reforestation process.

economic importance (EIM) of forests. The third criterion is related to the impact of climate change (ICC) on the forest ecosystem (Garcia-Lopez and Allue-Camacho 2010).

For the first criterion, that is, the effect on various environmental services, the following subcriteria are considered:

- Contribution to biodiversity (CB). This refers to the uniqueness of a vegetation type, which cannot be found elsewhere or under different conditions (Cram *et al* 2006). Concepts such as autochthony, gregariousness, species richness and maturity level are considered here. Ruiz-Benito *et al* (2013) claim that differences in species richness between planted forests and natural ecosystems might be reduced through management options, allowing more natural conditions to be restored.
- Landscape enhancement (LE). Chromatic heterogeneity, average height from the upper storey and gap distribution patterns might be included in this concept (Gomontean *et al* 2008). Forest management towards more naturalness and wilderness may enhance the landscape (Lupp *et al* 2013). On the other hand, Moreno *et al* (2011) report that landscape variables such as land-cover type, distances to roads and towns, aspect or elevation might influence forest risk.
- TA may be defined here as the response of society to the condition of the environment (Roura-Pascual *et al* 2009), including social acceptance of the species. The public has a right of access for recreational purposes and of indicating the intensity of use. On the other hand, Edwards *et al* (2012a) have carried out a survey of public preferences for forests as sites for recreational use and define recreational value of a forest in terms of the preference of people who regularly use forests as recreation sites.
- Wildlife improvement (WI) refers to the conditions for setting wildlife species in the area. Dietz and Jorgenson (2014) suggest that high levels of human well-being are associated with low pressure on the environment. Ezebilo (2012) studies forest stakeholder participation in improving wildlife habitat in planning a more sustainable forest strategy which integrates wildlife. Other studies assess the effects of forest management on wildlife (Nielsen and Treue 2012). Moreover, maintenance of other socio-economic functions and conditions of forests is required by the EU Forest Strategy (EUCOM 2013). The latter considers safeguarding the forests' natural habitats and their ecological functions to be an essential role.

In the second criterion, i.e. the economic importance of forests, the subcriteria considered take into account not only general factors mentioned in any reforestation project, but also those related to the significant economic value arising from the multiple benefits provided by biodiversity. According to the EU Biodiversity Strategy to 2020 (EUCOM 2011), these are seldom seized by markets. In this context, the general recommendations for forestation and reforestation projects of the Ministerial Conference on the Protection of Forests in Europe (MCPFE 2007) encourage their contribution to maintaining or improving the provision of ecosystem goods and services. The proposed subcriteria are:

- Initial cost (IC) includes items such as soil preparation cost, planting cost, vegetation clearing, and other socio-economic factors (Barajas-Guzman and Barradas 2013). It also includes replanting cost. Government incentives, subsidies or any financial compensation are taken into account (Zhou *et al* 2007).
- The subcriterion of silvicultural treatments (ST) includes the number and cost of later silvicultural interventions, such as thinning and harvesting regimes (Edwards *et al* 2012b). These ST have a positive effect on the survival and growth of seedlings (Navarro-Cerrillo *et al* 2011). Silvicultural operations may have either positive or negative effects on biodiversity and water protection without high cost (Koprowski and Dunker 2012). Thus, it is important to anticipate the long-term effects of ST in order to develop a sustainable forest management.
- Economic return (ER) refers to the valuation of both market and non-market services, including environmental externalities (Mendoza and Martins 2006) since forests provide important ecosystem services which supply societal needs. On the one hand, Ojea *et al* (2012) compare the economic returns of a sustainable and a non-sustainable forest by analyzing long term trends, showing that sustainable forests yield higher economic benefits. On the other hand, Xu *et al* (2013) estimate the potential of carbon storage in the live biomass of forest in order to reduce emissions of carbon dioxide by restoring cleared and disturbed spruce forest though afforestation and reforestation programs.

The third criterion, i.e. the impact of climate change on forests, includes subcriteria which increase forest ecosystem vulnerability as a result of climate change. These may be declining soil fertility and water availability and increasing risks of forest fires (Kukavskaya *et al* 2013) especially in the Mediterranean regions (Schröter *et al* 2005). Moreover, due to rising temperatures and hotter and drier summers, wildfires are forecast to increase in frequency, intensity and severity (Vautard *et al* 2014). In fact, evidence of the relationship between drought and forest fires has been reported by Vazquez *et al* (2002) in Northern Spain, regarding the active hot spots detected in the satellite during the four summer months of the year 2000. Other effects of climate change such as droughts, tree mortality, loss of biodiversity and vegetation stress produce increasing fuel loading, insect outbreaks and the spread of invasive species (Vicente-Serrano *et al* 2014). In IPCC 2014a, 2014b Working Group II Fifth Assessment Report, vulnerability is defined as the propensity or predisposition to be adversely affected, which includes concepts such as sensitivity or susceptibility to harm and lack of adaptation to those effects produced by climate change. In the context of forests, impacts attributed to climate change are: increasing burnt forest areas, wildfire frequency and duration; regional increases in tree mortality and insect infestations in forests; rainforest degradation and recession. Reforestation is considered, among other actions, as a policy of adaptation to these impacts, otherwise forest dieback involves risk for carbon storage, biodiversity, wood production, water quality, amenity and economic activity. This adaptation can only occur through policies taking into account rural decision-making contexts which valuates non-marketed ecosystem services. Trees may be adapted to future climate changes throughout their phenotypic plasticity (Benito Garzon *et al* 2011). Other attributes of species, such as ecological resistance (capacity to maintain integrity under stress) and resilience (capacity to reestablish after disturbance) can attenuate the effects of climate change. Thus, the following subcriteria have been taken into account:

- Water stress response (WR). In the west Mediterranean basin, water stress is considered the most limiting factor for ecosystem reconstruction and the main factor of forest decline (Sanchez-Salguero *et al* 2012). The effects of climate change are rising temperatures, decreasing rainfall and concentration of rainfall in extreme events. Urbieta *et al* (2008) suggest that tree species can differ in their responses to water availability during the phase of establishment.
- Sunlight tolerance (SU). Species tolerate and require a specific amount and period of sunlight at an early age in order to continue their successful development (Peman Garcia *et al* 2006). Sanchez-Gomez *et al* (2006) reported the survival of seedlings of different species under experimental gradients of irradiance and water availability. On the other hand, under sunny conditions, evaporation and transpiration are increased and less water is retained in the soil (Kaya and Kahraman 2011).
- Soil conservation (SC). Reforestation contributes to the prevention of soil erosion since trees intercept rain and slow down the water hitting the soil, which is the umbrella function. Moreover, the soil anchor

function of the roots prevents the soil from washing away (Kaya and Kahraman 2011). Consequently, these functions contribute to soil erosion prevention. Eventually, forest fire can affect soil properties such as aggregate stability, organic matter content, soil microbiology, water repellency and soil mineralogy (Mataix-Solera *et al* 2011). Selkimaki *et al* (2012) studied the parameters of forests that are related to surface erosion, associated with climatic conditions, tree species composition and stand structure.

- Forest fire response (FR). Forest fires affect the production of water in the watersheds (Kinoshita and Hogue 2015). Some non-serotinous species, such as *Pinus nigra*, have very low or nil post-fire regeneration (Espelta *et al* 2003), which is taken into account in the framework of assessing the best alternatives. Moreover, the importance of fire in stimulating population growth of some serotinous species (*Acacia* sp., *Pinus halepensis, Pinus pinaster*) and its effect on stimulating germination of soil-stored seeds are important factors when assessing alternatives (Roura Pascual *et al* 2009). Gonzalez and Pukkala (2007) analyzed relationships between forest characteristics such as species composition and the probability of fire occurrence.

- Pests and diseases risk (PR). Biotic and abiotic damaging agents are forest disturbances, especially in vegetation with a slow growth rate, long life cycle and long reproductive periods (Cram *et al* 2006). Besides, the management effects on natural ecosystems may not be immediately apparent, and considerable periods may elapse before the long-term effects of anthropogenic perturbations become clear (Reilly and Elderd 2014).

Thus, three criteria can be distinguished in the hierarchical model. EES considers the effect on several environmental services, EIM includes some economic factors and ICC takes into account the impact of the climate change on forests. For each criterion and subcriterion, species are ranked to obtain an overall preference percentage for them. AHP methodology is required to evaluate these criteria in order to assign a specific priority to each factor and to evaluate the relative importance of the species in terms of each criterion and subcriterion.

4. Evaluation of expert judgments and pairwise comparison

The process is performed in three stages. In the first step, the three criteria are compared in pairs by the panel of experts using a questionnaire with a 9-point scale (see table 1). Higher values indicate a greater priority and reciprocals are used to show their preference for the inverse choice (Curiel-Esparza and Canto-Perello 2013, Martin-Utrillas *et al* 2015c). The panel of experts is requested to assess the three criteria as is shown in table 2. The priorities of each group are established in this way, providing as a result a pairwise comparison matrix of the criteria EES, EIM and ICC:

$$[M] = \begin{bmatrix} 1.0000 & 0.9583 & 0.3476 \\ 1.0435 & 1.0000 & 0.2231 \\ 2.8769 & 4.4815 & 1.0000 \end{bmatrix}. \quad (1)$$

Thereafter, the priority vector constituted by the percentages of overall relative priorities can be obtained by the eigenvector method:

$$[\omega] = \begin{bmatrix} 0.1897 \\ 0.1684 \\ 0.6419 \end{bmatrix}. \quad (2)$$

In order to evaluate how coherent the panel of experts is with respect to their answers, a consistency analysis is developed calculating the eigenvalue ($\lambda_{\max} = 3.0263$) to obtain the consistency ratio (CR). Then, the consistency index is defined as:

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1} = 0.0131, \quad (3)$$

where n is the order of the matrix. The random consistency index (RCI) for $n = 3$ is 0.52 (Saaty 2012). Therefore, the CR is calculated as follows:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RCI}} = 2.53\%. \quad (4)$$

Maximum CR values are given depending on n value. In this case ($n = 3$), CR must be below 5%, hence the results are reliable.

In the second survey, the panel of experts is requested to compare the twelve subcriteria as shown in table 2. Subcriteria in each group are assessed in order to determine their relative weights, using the eigenvector method (see table 3 and figure 2). Once again, the priorities of each subcriterion within each criterion are established to evaluate their weight. In this case, the pairwise comparison matrix of the four subcriteria in the first criterion (EES) for the panel of experts is as follows:

$$\left[M_{\mathrm{EES}}\right] = \begin{bmatrix} 1.0000 & 2.9808 & 8.3922 & 6.9880 \\ 0.3355 & 1.0000 & 6.8525 & 4.4922 \\ 0.1192 & 0.1459 & 1.0000 & 0.3704 \\ 0.1431 & 0.2226 & 2.6999 & 1.0000 \end{bmatrix}. \quad (5)$$

The eigenvector method is applied, pointing out the percentages of overall relative priorities for each factor on the EES criterion:

$$\left[\omega_{\mathrm{EES}}\right] = \begin{bmatrix} 0.5836 \\ 0.2848 \\ 0.0455 \\ 0.0860 \end{bmatrix}. \quad (6)$$

And the parameters of the consistency analysis in this case adopt the following values: 4.1390 for the $\lambda_{\max}$, the RCI (CI = 0.0463) and the CR (CR = 5.21%), which is below 9% for $n = 4$ in this case, so it can be

Table 1. Saaty's fundamental scale for pairwise comparisons used by the panel of experts in the APH methodology (Saaty 2012).

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors or technologies contribute equally to the goal
3	Moderate importance	Experience and judgment slightly favor one factor or technology over another
5	Strong importance	Experience and judgment strongly favor one factor or technology over another
7	Very strong or demonstrated	A factor or technology is favored very strongly over another
9	Extreme importance	The evidence favoring one factor or technology over another is of the highest posible order of affirmation
1/3 1/5 1/7 1/9	Reciprocals of above	If factor or technology i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i

Table 2. Questionnaire given to the panel of experts in order to evaluate criteria and subcriteria in a pair-wise comparison, according to the Saaty's fundamental scale shown in table 1.

Main groups	More important than				Equal	Less important than				Main groups
EES	9	7	5	3	1	3	5	7	9	EIM
EES	9	7	5	3	1	3	5	7	9	ICC
EIM	9	7	5	3	1	3	5	7	9	ICC
CB	9	7	5	3	1	3	5	7	9	LE
CB	9	7	5	3	1	3	5	7	9	TA
CB	9	7	5	3	1	3	5	7	9	WI
LE	9	7	5	3	1	3	5	7	9	TA
LE	9	7	5	3	1	3	5	7	9	WI
TA	9	7	5	3	1	3	5	7	9	WI
IC	9	7	5	3	1	3	5	7	9	ST
IC	9	7	5	3	1	3	5	7	9	ER
ST	9	7	5	3	1	3	5	7	9	ER
WR	9	7	5	3	1	3	5	7	9	SU
WR	9	7	5	3	1	3	5	7	9	SC
WR	9	7	5	3	1	3	5	7	9	FR
WR	9	7	5	3	1	3	5	7	9	PR
SU	9	7	5	3	1	3	5	7	9	SC
SU	9	7	5	3	1	3	5	7	9	FR
SU	9	7	5	3	1	3	5	7	9	PR
SC	9	7	5	3	1	3	5	7	9	FR
SC	9	7	5	3	1	3	5	7	9	PR
FR	9	7	5	3	1	3	5	7	9	PR

acceptable. The same procedure is undertaken for the subcriteria in the other two criteria, i.e. economic importance and impact of climate change on the forest.

In the third step, the selected species must be prioritized in relation to each subcriterion. Then, the pairwise comparison and weighting procedure is undertaken. For the third criteria and for each of the five subcriteria, a prioritized list of species is obtained (see table 4). Once the eigenvectors for each subcriterion have been calculated with an acceptable level of consistency, the matrix of priority vectors for species and subcriteria can be constructed as shown in table 5. Figure 2 represents the factor's weight assigned to each subcriterion as a result of applying the eigenvector method in the pairwise comparison from the panel of experts. The priority matrix of the species for each subcriterion must be multiplied by the priority matrix of this subcriterion in order to obtain an overall prioritized list of species. Figure 3 shows the optimal percentage distribution of the appropriate species to be used in the reforestation planning.

5. Conclusions

Climate change is not usually taken into account as a key factor in a specific stand of reforestation. Moreover, there is a lack of agreement on the weight of each species in a reforestation project, which is usually calculated in a discretionary way. Consequently, the success of a reforestation project is based mainly on experience learned by trial and error. Long-term tree regeneration demands somewhat more accuracy in the decision-making process. The proposed hybrid methodology with its consistency analysis can reduce

Table 3. Results from subcriteria pairwise comparisons using a 1–9 preference scale for each expert respect to the overall goal.

	Results for every expert											
Pairwise criteria	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
CB versus LE	5	7	1/5	9	5	1/3	9	9	9	9	5	1/7
CB versus TA	7	9	5	9	9	9	9	9	9	9	9	9
CB versus WI	5	7	1	9	9	9	9	9	9	9	9	9
LE versus TA	5	7	5	7	9	7	5	7	9	7	9	7
LE versus WI	5	5	3	7	5	5	7	9	7	1/3	7	5
TA versus WI	3	1/3	3	5	1	1/7	1/9	1/7	1/9	1/7	1/9	1/9
IC versus ST	3	1/3	5	1	1/3	1/3	1	1	1	1	1	1
IC versus ER	3	7	3	5	1/5	9	9	9	9	7	7	7
ST versus ER	3	9	7	7	3	9	9	7	7	7	9	9
WR versus SU	3	3	1	5	3	3	5	5	3	7	1/3	5
WR versus SC	1/3	1/5	1	1/5	1/3	1/5	1/5	1/3	1/7	1/5	1/5	3
WR versus FR	1/7	1/7	1/7	1/9	1/7	1/7	1/7	1/9	1/9	1/9	1/9	1
WR versus PR	1/5	1/3	1/5	1/7	1/3	1/7	1/5	1/7	1/7	1/9	1/7	3
SU versus SC	1/5	1/3	1/5	1	1/5	1/7	1	1/3	1/7	3	1/7	1/5
SU versus FR	1/9	1/7	1/9	1/5	1/7	1/9	1/7	1/7	1/9	1/9	1/3	1/9
SU versus PR	1/7	1/5	1/5	1/5	1/7	1/3	1/5	1/9	1/7	1/7	1/9	3
SC versus FR	1/3	1/3	1/7	1/5	1/5	1/3	1/5	1/5	1/5	1/3	1/5	1/7
SC versus PR	1/3	1/3	1/7	1	1/5	1/5	1/5	1/3	1	1/3	1/3	1/7
FR versus PR	3	1	5	3	3	3	5	3	7	5	1/7	7

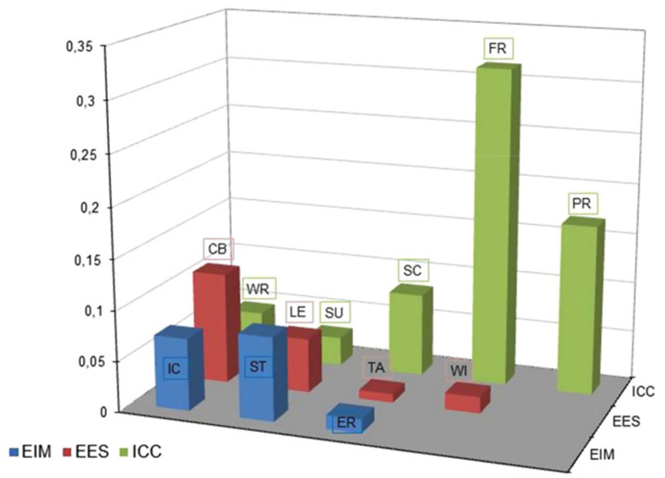

Figure 2. Relative importance assigned to each subcriterion for the three main criteria (EIM, EES, ICC) applying the eigenvector method in the pairwise comparison matrix.

random choices and integrate climate change criteria in the reforestation project.

Due to the large number of factors considered and the complexity of the system, reforestation planning requires decision makers to use multicriteria analyses in order to assess potential species for their suitability according to the criteria considered. Despite the variety of potential species for a reforestation project, the Delphi-AHP methodology described allows decision makers to focus on those providing a better suitability in each stand. At present, not only economic criteria are taken into account in reforestation but also those providing environmental services to society, always bearing in mind the criteria which might be related to climate change, as promoted by the European Commission.

Not every factor in this study may have the same weight in the decision-making process. Therefore, the factors are assigned a weight based on the characteristics of the case studied, i.e. reforestation aimed at conserving biodiversity in the Mediterranean region. It is precisely in this assessment that the flexibility of this technique resides. As it can be observed in figure 2, the first column of each color shows the accumulated weight given for each subcriterion. The highest values correspond to FR (fire forest response) and PR (pests and diseases risk) because of the increasing importance of the impact of climate change. The

Table 4. Pairwise comparison matrix, eigenvector and consistency analysis for the six species with respect to each subcriteria of the ICC criteria.

RL_519886	Species	*Q. ilex*	*Q. faginea*	*F. ornus*	*P. spinosa*	*S. aria*	*C. monogyna*	Eigenvector
WR	*Q. ilex*	1.0000	8.6308	7.2994	8.6308	7.1481	5.4388	0.5426
	Q. faginea	0.1159	1.0000	1.0959	2.7375	0.3215	0.2306	0.0510
	F. ornus	0.1370	0.9125	1.0000	2.8566	0.3501	0.3355	0.0557
	P. spinosa	0.1159	0.3653	0.3501	1.0000	0.2059	0.1470	0.0278
	S. aria	0.1399	3.1105	2.8566	4.8568	1.0000	0.1866	0.1025
	C. monogyna	0.1839	4.3371	2.9808	6.8018	5.3603	1.0000	0.2203
		$\lambda_{max} = 6.5617$ CI $= 0.1123$ CR $= 8.99\% < 10\%$ $(n = 6)$						
SU	*Q. ilex*	1.0000	6.7583	6.6183	4.9279	3.2666	1.2009	0.3331
	Q. faginea	0.1480	1.0000	4.7225	0.3236	0.1866	0.1159	0.0498
	F. ornus	0.1511	0.2118	1.0000	0.2178	0.1814	0.1380	0.0279
	P. spinosa	0.2029	3.0906	4.5919	1.0000	0.3676	0.1351	0.0816
	S. aria	0.3061	5.3603	5.5128	2.7200	1.0000	0.3501	0.1559
	C. monogyna	0.8327	8.6308	7.2478	7.4012	2.8566	1.0000	0.3517
		$\lambda_{max} = 6.5690$ CI $= 0.1138$ CR $= 9.10\% < 10\%$ $(n = 6)$						
SC	*Q. ilex*	1.0000	1.3161	2.7200	2.6067	6.9014	6.7583	0.3346
	Q. faginea	0.7598	1.0000	2.8566	3.1305	6.8065	6.7583	0.3169
	F. ornus	0.3676	0.3501	1.0000	2.8566	2.8566	2.8566	0.1536
	P. spinosa	0.3836	0.3194	0.3501	1.0000	2.6067	3.1305	0.1050
	S. aria	0.1449	0.1469	0.3501	0.3836	1.0000	1.0959	0.0461
	C. monogyna	0.1480	0.1480	0.3501	0.3194	0.9125	1.0000	0.0438
		$\lambda_{max} = 6.1486$ CI $= 0.0297$ CR $= 2.38\% < 10\%$ $(n = 6)$						
FR	*Q. ilex*	1.0000	0.1883	2.5736	4.6981	1.2211	6.5338	0.1901
	Q. faginea	5.3095	1.0000	7.2708	6.3862	1.2211	6.5846	0.4127
	F. ornus	0.3886	0.1375	1.0000	0.8189	0.1591	1.3493	0.0498
	P. spinosa	0.2129	0.1566	1.2211	1.0000	0.1643	0.3038	0.0403
	S. aria	0.8189	0.8189	6.2858	6.0874	1.0000	6.5846	0.2532
	C. monogyna	0.1530	0.1519	0.7411	3.2920	0.1519	1.0000	0.0539
		$\lambda_{max} = 6.5572$ CI $= 0.1114$ CR $= 8.91\% < 10\%$ $(n = 6)$						
PR	*Q. ilex*	1.0000	4.7225	7.2994	2.8566	6.7583	1.0959	0.3091
	Q. faginea	0.2118	1.0000	4.7225	2.9808	2.7375	0.1380	0.1129
	F. ornus	0.1370	0.2118	1.0000	0.2934	0.3061	0.1159	0.0274
	P. spinosa	0.3501	0.3355	3.4087	1.0000	4.5919	0.1370	0.0883
	S. aria	0.1480	0.3653	3.2666	0.2178	1.0000	0.1159	0.0434
	C. monogyna	0.9125	7.2478	8.6308	7.2994	8.6308	1.0000	0.4190
		$\lambda_{max} = 6.6223$ CI $= 0.1245$ CR $= 9.96\% < 10\%$ $(n = 6)$						

Table 5. Summary of the factor's priority and the species' weights for each subcriterion.

			Selected species					
Criterion	Sub-criterion	Sub-criterion's weight	*Q. ilex*	*Q. faginea*	*F. ornus*	*P. spinosa*	*S. aria*	*C. monogyna*
EES	CB	0.111	0.032	0.045	0.445	0.304	0.069	0.105
	LE	0.054	0.035	0.065	0.393	0.307	0.068	0.133
	TA	0.009	0.106	0.037	0.411	0.348	0.032	0.067
	WI	0.016	0.291	0.121	0.029	0.090	0.044	0.425
EIM	IC	0.072	0.031	0.045	0.278	0.453	0.082	0.111
	ST	0.083	0.032	0.031	0.296	0.459	0.071	0.112
	ER	0.014	0.237	0.111	0.038	0.542	0.034	0.037
ICC	WR	0.046	0.543	0.051	0.056	0.028	0.102	0.220
	SU	0.029	0.333	0.050	0.028	0.082	0.156	0.352
	SC	0.083	0.335	0.317	0.154	0.105	0.046	0.044
	FR	0.315	0.190	0.413	0.050	0.040	0.253	0.054
	PR	0.169	0.309	0.113	0.027	0.088	0.043	0.419

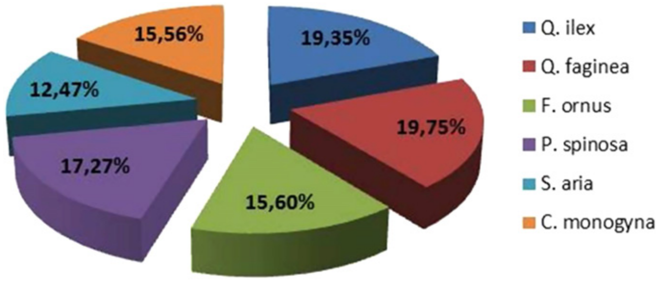

Figure 3. Optimum percentage distribution of the selected species for the reforestation.

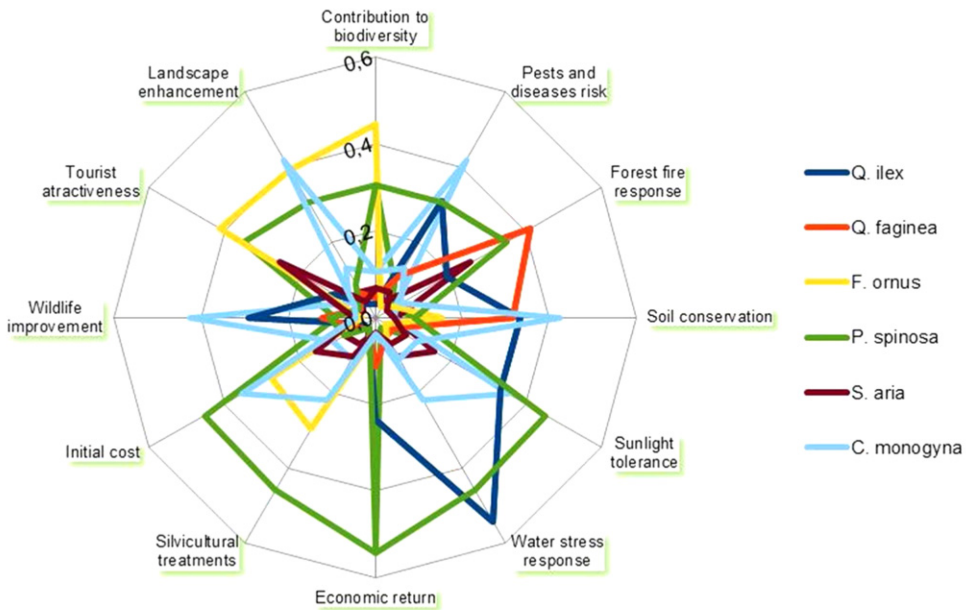

Figure 4. Species assessment for each subcriterion proposed by panelists as a result of applying the AHP method.

subcriterion CB (conservation of biodiversity) is in third position in line with the aim of reforestation. As regards the economic criteria, experts have given more importance to those targeting the success of reforestation, like IC and ST.

The results in table 5 show that *F. ornus* and *Prunus spinosa* are the most suitable species for almost all subcriteria of the first criterion (0.4452 and 0.3044 respectively for CB, 0.3929 and 0.3069 for LE, 0.4107 and 0.3481 for TA), while for WI the highest values are for *C. monogyna* (0.4245) and *Quercus ilex* (0.2910). For the economic subcriteria the species considered best is again *P. spinosa* (0.4530 for IC, 0.4587 for ST and 0.5417 for ER), followed by *F. ornus* (0.2776 for IC and 0.2957 for ST). However, for ICC subcriteria *Q. ilex* is best placed (0.5426 for WR, 0.3331 for SU, 0.3346 for SC, 0.3091 for PR); the same happens with *Quercus faginea* (0.3169 for SC and 0.4127 for FR) and with *C. monogyna* (0.2203 for WR, 0.3517 for SU and 0.4190 for PR). Therefore, as can be observed in figure 3, the most suitable species for all the subcriteria studied are *Q. faginea* (19.75%) and *Q. ilex* (19.35%).

The assessment of the species selected under each criterion considered in the reforestation is shown in figure 4. The results demonstrate that some species, such as *Q. ilex*, *Q. faginea* or *P. spinosa*, offer a good balance between all the factors that might affect the success and viability of reforestation. Finally, the optimal percentage distribution of the species selected is highlighted in figure 3. Reforestation planning can be accomplished with several species according to the percentages achieved. This decision-support system provides a methodology to give support and coherence to the process of selecting species in a reforestation. In an increasingly complex world, we are forced every day to deal with complicated issues involving several variables or stakeholders that might interact. Reforestation planning is no exception. Moreover, there is a lack of knowledge on how to implement climate-change factors. The proposed hybrid methodology allows the joint analysis of both traditional and climate-change criteria in reforestation projects.

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