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Title: The use of scenarios and models to evaluate the future of nature values and ecosystem services in Mediterranean forests.

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Abstract

Science and society are increasingly interested in predicting the effects of global change and socio-economic development on natural systems, to ensure maintenance of both ecosystems and human wellbeing. The Intergovernmental Platform on Biodiversity and Ecosystem Services has identified the combination of ecological modelling and scenario forecasting as key to improving our understanding of those effects, by evaluating the relationships and feedbacks between direct and indirect drivers of change, biodiversity and ecosystem services.

Using as a case study the forests of the Mediterranean basin (complex socio-ecological systems of high social and conservation value), we reviewed the literature to assess (1) what are the modelling approaches most commonly used to predict the condition and trends of biodiversity and ecosystem services under future scenarios of global change? (2) what are the drivers of change considered in future scenarios and at what scales? (3) what are the nature and ecosystem services indicators most commonly evaluated?

Our review shows that forecasting studies make relatively little use of modelling approaches accounting for actual ecological processes and feedbacks between different socio-ecological sectors; predictions are generally made on the basis of a single (mainly climate) or a few drivers of change; in general, there is a bias in the set of nature and ecosystem services indicators assessed; in particular, cultural services and human wellbeing are greatly underrepresented in the literature. We argue that these shortfalls hamper our capacity to make the best use of predictive tools to inform decision-making in the context of global change.

Keywords: Ecological forecasting; Future Scenarios; Global Change; Impact Assessment Evaluations; IPBES; Nature Benefits to People; Socio-ecological systems

1. Introduction

Anticipating changes in biodiversity and the services that ecosystems provide to society has been a key goal of the environmental research (Clark et al. 2001), especially since the publication of the Millennium Ecosystem Assessment reports in 2005 (MEA 2005). With rapidly accelerating global changes associated to human activities this task has also become a key challenge for society in general (Vihervaara et al. 2010; Cardinale et al. 2012), motivating the recently published regional assessments on biodiversity and ecosystem services by the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) (https://www.ipbes.net/assessment-reports). Despite the growing scientific efforts, some of the knowledge gaps identified back in the 2005 MEA reports still exist. For example, we still have little understanding of the interactions and feedbacks between the drivers of ecosystem and biodiversity change and multiple aspects of human well-being, like human health and food security (Pecl and et al 2017; IPBES 2018a). Also, the models used to characterize the relationships between biodiversity and ecosystem services (ES) mostly rely on linear correlations and do not consider non-linear changes, thresholds and tipping points in ecosystems (Ricketts et al. 2016; Lavorel et al. 2017). To address these challenges, the IPBES identifies the use of future scenarios and modelling approaches as fundamental pillars to advance in the understanding of the relationships and feedbacks between direct and indirect drivers of change, biodiversity, ecosystem services (considered through the lens of nature benefit´s to people; Díaz et al. 2015) and aspects conditioning good quality of life (IPBES 2016).

A scenario is a coherent, internally consistent and plausible description of a possible future state of the world (Nakicenovic et al. 2000). Built upon scientific understanding of past and current observed relationships between drivers and environmental trends, scenarios draw upon narratives (storylines) of plausible socio-economic developments or particularly desirable future pathways (visions) under specific policy options and strategies (Alcamo and Ribeiro 2001; Peterson et al. 2003; O´Neill et al. 2015; Bai et al. 2016). One of the main challenges of using scenarios for predicting future impacts of societal development on ecosystems is the translation of scenario

narratives into quantitative model input variables (Kok et al. 2015). In this regard, the rapid advances in science and observation of climate change have favored the widespread incorporation of climatic variables as direct drivers in regional-scale scenarios and future projections, especially in impact assessments (Moss et al. 2010). In contrast, substantial research is still needed about the inclusion of other important short-term drivers of biodiversity and ecosystem change such as land use, invasive species and pollution (FRB 2013; Titeux et al. 2016; Sirami et al. 2017; but see for example Malek et al. 2018). Multiple issues hamper the incorporation of those drivers of change in predictive approaches, including mismatching scales between the available data and the modelled process, the short temporal coverage of data, or the actual lack of quantitative data for some drivers (Hauck et al. 2015). Apart from incorporating multiple drivers of change, ecological models should, to the maximum possible extent, represent the complex interdependencies within human and environmental systems (e.g. consider the interactions and feedbacks between multiple economic sectors, e.g. Harrison et al. 2016); this normally requires the use of multiple interlinked models (model coupling or model integration) to account for the various processes operating at different spatial scales (Harfoot et al. 2014; Talluto et al. 2016).

Systems long exposed to human activities are particularly sensitive to this imbalance in the methods and approaches used to predict nature responses to global changes. In these systems, interactions between past land use changes (i.e. land use legacies) and current pressures, as well as the difficulty of untangling multiple causation are likely to require complex, integrated approaches (see Figure 1). Mediterranean forests are a good example of such systems, because they have been subjected to a long history of use and transformation (Nocentini and Coll 2013). They are biodiversity-rich, complex socio-ecological systems that have been continuously adapting to use and exploitation throughout many centuries, while providing important services and goods to society (Myers et al. 2000; Gauquelin et al. 2018). Currently, they cover approximately 25 % of the Mediterranean region (Malek and Verburg 2017). Conservation of these systems must deal with multiple cultural, ecological and economic values, and complex

dynamics of social change are likely to be exacerbated by global change (Doblas-Miranda et al. 2015).

In this study, we assess to which extent, the integration of drivers described in Figure 1 is being achieved in predictive exercises of Mediterranean forest systems. These represent a prime case study to evaluate the state of the art and the remaining gaps in the use of models and scenarios to investigate the effects of global change on biodiversity and ecosystem functioning. We review studies using ecological models to predict global change environmental impacts in forest systems in the Mediterranean basin during the last three decades to answer the following questions: (1) What are the modelling approaches most commonly used? We assess whether correlative approaches - those based on statistical relationships among drivers and a response variable – are superseded by more integrative approaches such as process-based models – those explicitly incorporating knowledge of ecological processes – or integrated models – those combining multiple systems, modelling approaches and accounting for feedbacks among different parts of the modelled system. (2) How are specific drivers being included in modelled scenarios (e.g. are models considering multiple drivers and scales)? (3) How holistic is our knowledge about the effects of global change on nature and people? Biodiversity and ecosystem services' indicators are used to assess the condition and trends of earth's systems (through monitoring of species, ecosystem functions, etc.), and represent essential tools for managers and politicians to track the consequences of decisions as well as to measure progress towards sustainable development (e.g. Aichi targets, Sustainable Development Goals; Brooks et al. 2015; Convention on Biological Diversity 2015; Geijzendorffer et al. 2017). Here we evaluate the types of indicators used to predict future condition of Mediterranean forest ecosystems, and whether these cover a wide variety of aspects of forest systems. On the basis of our review, we highlight outstanding knowledge gaps and biases, identify priority areas for research in ecological forecasting (the field of Ecology dedicated to predict how ecosystems will change in the future in response to environmental factors) and discuss a potential way forward.

2. Materials and methods

In June 2016, we conducted a systematic review of studies assessing future changes in forest ecosystems in the Mediterranean basin. We searched the Web of Science database for peer-reviewed articles published between 1990 and 2016 that used modelling or simulation approaches to predict future values/change of nature indicators (e.g. species richness, ecosystem functions, etc.) or ecosystem services (ES) indicators linked to Mediterranean forests. The list of databases, keywords and filters used for the literature selection is detailed in Table 1. This search yielded 2424 articles. We reviewed the abstracts to remove duplicates and articles clearly outside the thematic or spatial scope of this study (2029 articles) (Online Resource 1). Exclusion criteria included: articles focusing on the Mediterranean biome but outside the Mediterranean basin (e.g. California, Australia); articles that used models to make inference about ecological processes (e.g. how does drought affect forest growth?) but did not explicitly use scenarios to make future predictions of the indicator; experimental studies (e.g. the study sets vegetation plots where a species X is subjected to increases of 1, 2 and 3 degrees of temperature or to drought stress, to evaluate the effect of increasing temperatures in species growth, reproduction, etc.); studies focused on exotic species located in Mediterranean countries (e.g. *Eucalyptus* spp.) and articles focusing on non-Mediterranean forests within any of the evaluated countries (on the basis of the dominant species and the geographic location of the study area; e.g. beech forests in Normandy). After reading the full-texts of the remaining 395 articles, we excluded an additional 232 studies following the same criteria listed above, leading to a final set of 163 articles that were retained for analysis (Online Resources 1, 2).

For each article, we extracted information about the geographic location of the study area, the modelling approach, the scenarios used and their origin, the drivers of change considered in each scenario, the spatial scales addressed in each study, and the nature and ES indicators evaluated. We generated a unique record for each scenario-indicator combination within each of the articles read. This led to a total of 2075 entries in the database. We calculated summary statistics (frequencies) regarding the above-mentioned fields in our database. Table 2 provides a complete list of the information extracted, together with the criteria used for classification.

3. Results

3.1. Geographic coverage

The majority of articles selected in our review (133 articles; 82 %) corresponded to national, sub-national or local studies carried out within the North-Western countries of the Mediterranean basin (Portugal, France, Italy and Spain; Figure 2). In addition, our review included twelve global or European-wide studies with detailed results for at least one country within the Mediterranean zone, 14 regional studies (focused on two or more countries of the Mediterranean basin), one study with detailed results for the Afro-Mediterranean domain and three studies based on simulated Mediterranean-type landscapes (Online Resource 3).

3.2. Scenarios and drivers

The majority of studies (74.2%) used two or more scenarios when making future predictions of nature and ES indicators, while only 25.8% of studies used a single scenario (93 % of these are also based on a single driver only, mostly a climatic driver). More than half of the scenarios assessed were based on a single-driver only (56%), with climate the most frequently used driver (31.9% of the scenarios were based on climate only; Figure 3a). The second most used driver was management (e.g. different thinning regimes, levels of biomass extraction, etc.), with 13 % of the scenarios, followed by fire (6.2%) and land-use/land-cover change (LULCC; 4.2%). Less than 1% of the single-driver scenarios used drivers other than the previously mentioned (e.g. invasive species). In total, 62.8% percent of scenarios used climate as a driver (either as solo-driver or in combination with other drivers), whereas the other main drivers found (fire, LULCC and management) were considered in less than 30 % of the scenarios (Figure 3b). When multi-driver scenario combinations were used (Figure 3b), fire was most often combined with either climate and/or LULCC, whereas LULCC was most often combined with climate and/or fire, and management was mostly combined with climate and, to a lesser extent, with fire.

We did not find a particular general pattern regarding the spatial extent of the study area (global/EU wide, regional –Pan-Mediterranean-, national, subnational or local) and the number of drivers considered in the scenarios. The exception was regional (Pan-Mediterranean) studies,

in which scenarios were always based on a single driver only (mostly climate). This lack of a clear pattern could also be due to the imbalance in representation of scales across the selected articles. However, there were differences in the types of drivers used: whereas global/EU wide studies mostly focused on climate and land use change as main drivers, sub-national and local scale studies mainly incorporated fire and management/disturbance. Moreover, studies carried out at large scales (national, regional or global) generally made predictions based on available scenarios (e.g. IPCC), whereas user-made scenarios were more common at sub-national or local scales (Online Resource 3).

3.3. Modelling approaches

Correlative and process-based/integrated approaches were almost equally represented when modelling either nature or ecosystem services indicators (Figure 4a); the few studies that evaluate nature and ecosystem indicators (3% of the total) used predominantly process-based or integrated approaches (Figure 4a, b). Studies based on process-based or integrated approaches accounted for two or more drivers of change with higher frequency than studies based on correlative/empirical approaches (Figure 4b).

3.4. Nature and Ecosystem services indicators

We found an unequal use of ES and nature indicators within the set of selected articles: 57 % of the studies evaluated ES indicators only, 40 % evaluated nature indicators-only, whereas the remaining 3% evaluated both types of indicators simultaneously (Figures 4a, 5). Of all studies assessing ES indicators, 60% focused on regulation & maintenance services, almost evenly split between climate change regulation and the maintenance of physical, chemical and biological conditions (Figure 5). Almost all the remaining ES studies (38%) focused on provisioning services, mostly on indicators of plant materials for direct use and processing (e.g. timber, 82.6%; Figure 5). Cultural services, integrative ES indicators and other regulating services were only marginally represented (Figure 5). Fire risk, understood here as a regulating & maintenance service, was evaluated in 25 articles (approx. 15% of the total selected articles). All ES indicators found referred to the supply capacity of forest to provide services and none to the demand side.

Almost 80% of the nature indicators evaluated corresponded to measures of species/population trends, such as changes in species abundance, geographical range, etc. (Figure 5); 10% focused on measures of compositional intactness such as forest cover extent, changes in landscape configuration, etc.; whereas only a few studies focused on measures of ecosystem functioning (e.g. forest traits, regeneration capacity) or extinction risk (e.g. allele diversity, viability of populations).

4. Discussion

Future conservation of biodiversity and of the natural capital will require an integrative, broad evaluation of all the challenges that nature will face under the current context of societal and environmental change. Our review shows that, despite the increasing use of scenarios and models as tools to explore those changes (Online Resource 4), the scientific community is still focusing efforts on a fraction of the overall challenges the future might bring to ecosystems and nature. This is reflected in the relatively low proportion of studies considering multiple-drivers operating at different spatio-temporal scales (44%), as well as the very low representation of studies assessing nature and ES indicators simultaneously (3%). Moreover, process-based or integrated modelling approaches are still far from being the norm (53.7%). In this study we wanted to examine what, how and where the current modelling work in the Mediterranean area is taking place. Further research should be devoted to the implications of the modelling approaches used to inform policy and decision-making, and in particular, to evaluate the trade-offs between model complexity and policy relevance (something we could not gather enough information on).

4.1. Geographic coverage

We found a strong geographic bias in the use of scenarios and models in Mediterranean forestry research, with few studies focusing in southern countries (Figure 2). This may stem in part from economic differences between countries of the two sides of the Mediterranean (Online Resource 5), which reflects in differences in their educational systems (i.e. Southern Mediterranean countries present a much lower ratio of post-graduate *vs.* bachelor students in forestry than northern ones), national research budgets (FAO and Plan Bleu 2013) and availability of experts

on the study of biodiversity and ecosystem service-related scenarios (IPBES 2018b). Our results might also reflect the importance (in terms of total coverage) of forest systems within each country (Online Resource 5). This unequal distribution of information across the North-South, West-East axes of the Mediterranean makes it difficult for the scientific community to make robust predictions at the level of the whole Mediterranean basin, especially for its southern part.

4.2. Scenarios and drivers

The literature reviewed showed a strong bias towards the evaluation of impacts of climate change on Mediterranean forest systems, especially in studies addressing questions at broad (national to global) scales (as recently observed in other studies; IPBES 2016, 2018a; Kok et al. 2017; Rosa et al. 2017). This bias might be explained by the fast development and public availability of global circulation models and climate scenarios (Moss et al. 2010) and the widespread use of IPCC climate projections to predict biodiversity patterns (Titeux et al. 2016; Sirami et al. 2017), and by the fact that the Mediterranean basin has been identified as a regional climate change hotspot (EEA 2005; Diffenbaugh and Giorgi 2012). We note that, in the literature selected, climate change impacts were always assessed through the change in long-term average climate conditions, mainly annual mean temperature and total rainfall. However, one of the main climate threats to Mediterranean ecosystems is the increase in the frequency and duration of extreme weather events (length of droughts, heatwaves, short periods of intensive raingall, etc.; Stocker et al. 2013). Extreme conditions can play an important role altering the structure and function of Mediterranean forests in the short term, compromising the services they provide (Peñuelas et al. 2017). For example, prolonged droughts can induce diebacks and favor a shift in species composition or the establishment of invasive species (Resco De Dios et al. 2007; Martínez-Vilalta and Lloret 2016), while the co-occurrence of heat waves and drought conditions can cause large wildfires with devastating consequences for people and the environment (Founda and Giannakopoulos 2009; Fernandes et al. 2016; Ruffault et al. 2018). Ignoring those extreme-weather threats might lead to misleading predictions about the future condition and trends of

species and ecosystems (Morán-Ordóñez et al. 2018), and therefore, of their benefits on human-wellbeing.

There is still little integration of key drivers of change other than climate in Mediterranean systems (Figure 1), such as fire, LULCC and management (Keeley et al. 2012), which impact ecosystems locally in the short- and mid-term and might have irreversible consequences in ecosystem health before the worst-case climate change scenario could be realized. For example, although forest fires are a growing environmental and societal issue in Mediterranean systems, integration – in scenarios and models – of fire as a driving force with other mid- and long-term drivers such as climate was only found in a few studies focused on local to sub-National scales or simulated landscapes (Pausas 2006; Pausas and Lloret 2007; Brotons et al. 2013; Pacheco et al. 2015; Gil-Tena et al. 2016; Górriz-Mifsud et al. 2016). Local and sub-national scales are ideal for an integrated analysis of processes operating at multiple scales (e.g. local fires and climate), which in turn is crucial to understand the resilience of ecosystems under global change conditions and thus guide sustainable development policies (Seidl et al. 2011). For this reason, local scales have been proposed as one of the starting points for the generation of a new set of multi-scale nature and ES scenarios frameworks to be developed by the IPBES community (Kok et al. 2017). Developing authoritative, integrated future scenarios of forests and associated land use changes, management practices and fire risks is becoming an urgent need in regions subjected to multiple pressures such as the Mediterranean.

Moreover, since driving forces of environmental problems can take such a wide range of different directions, it is good practice (if possible) to develop and test multiple scenarios that reflect different plausible trends, rather than testing a single scenario only as observed in 25.8% of the selected articles (Alcamo and Ribeiro 2001). Testing several scenarios improves our understanding of how different sources of uncertainty might impact our model/target system (Peterson et al. 2003; Mahmoud et al. 2009). This is particularly relevant for the case of *exploratory* or *prospective* approaches (all approaches used in our selected literature), that investigate upcoming changes that might significantly vary from past trends (McCarthy et al.

2011; Rieb et al. 2017). Despite the management of Mediterranean forests can contribute substantially to the achievement of the sustainability goals to which Mediterranean countries have committed (e.g. Aichi targets, Sustainable Development Goals, EU bioeconomy strategy, climate mitigation actions), none of the studies evaluated used target-seeking scenarios (scenarios that first set a vision of the future and then describe different pathways - e.g. management alternatives, policy options- that might lead to achieve the vision of the desired future). This might be because target-seeking scenarios for biodiversity have mainly been developed for the global to continental scales (e.g. Rio+20 scenarios in the Global Biodiverisity Outlook 4; Convention on Biological Diversity 2014).

4.3. Modelling approaches

Under the current context of environmental change, models integrating social, economic and environmental drivers are more likely to be policy-relevant (Seidl et al. 2011; IPBES 2016). Integration of various drivers at multiple spatio-temporal scales (Figure 1) might generally require process-based/mechanistic or integrated model approaches (Kelly et al. 2013; Harfoot et al. 2014) rather than correlative/empirical ones. Both correlative and process-based/integrated approaches were equally represented in our review, suggesting there is still room for a better integration of drivers across scales in the approaches currently used to evaluate the future of Mediterranean forests.

In a predictive framework, process-based approaches arguably bring advantages over correlative approaches, such as their ability to extrapolate beyond known conditions, which makes them particularly useful for making predictions under global change conditions (Cuddington et al. 2013). Process-based and integrated models also allow better exploration of interactions, feedbacks and trade-offs between different components of the modelled systems (e.g. trade-offs between conservation of natural values and production of provisioning services; Korzukhin et al. 1996), which are key for making well-informed decision making. However, the use of advanced integrative modelling approaches that explicitly combine multiple model types with an unique framework over different spatial scales is still rare (but see some examples at EU and global

scales: e.g. Böttcher et al. 2012; Kraxner et al. 2013). This is due to the inherent higher complexity of the former: generally, these are parameter- and data-intensive models, that require disciplinary expertise and prolonged time series of data for calibration and validation (Seidl et al. 2011; Harfoot et al. 2014; Rieb et al. 2017). Wider use of these complex approaches would require stronger collaborations between actors of different disciplines (from social sciences to climatology, agriculture and forestry) and knowledge holders (scientists, policy-makers, managers, citizens), and at different scales (e.g. from plant physiologists to macro-ecologists).

Nevertheless, the selection of modelling framework (decisions regarding the choice of model type, the complexity allowed, the spatio-temporal scales included, variables/drivers considered, etc.) should be ultimately determined by the ecological question addressed and the decision-context (with modelling stategies changing across the policy cycle; IPBES 2016). In most cases, this model selection will be limited by knowledge and data availability. As all models have strengths and weaknesses, a minimum requirement is that they are validated and uncertainty is evaluated (e.g. sensitivity analysis, multi-model ensembles) and communicated.

4.4. Nature and ecosystem services indicators

Most of the studies reviewed evaluated regulating and provisioning services. In the particular case of forests in the Mediterranean basin, this observed trend might respond to its recognized multifunctional character (Palahi et al. 2008): on the one hand, forests are (and have traditionally been) an important source of products for consumption and trade such as timber, fuelwood, truffles, pine nuts and cork for Mediterranean societies (FAO and Plan Bleu 2013). This might explain the interest in knowing what the future provision of these products will be in the coming decades. On the other hand, Mediterranean forests fulfill multiple regulation services of great interest for society, because of their direct influence in either the health of the system itself (through the maintenance of physical, chemical and/or biological conditions) and the wellbeing and socio-economic development of Mediterranean societies (e.g. soil erosion is one of the main environmental problems in European Mediterranean agro-forestry systems; García-Ruiz 2010). One of the regulating services most commonly evaluated in the selected literature was fire and

fire risk, a disturbance of increasing concern in fire-prone ecosystems (e.g. Mediterranean ecosystems) since it interferes with the continuous and sustainable provisioning of other ES (e.g. carbon storage; Seidl et al. 2014) and threats human safety (e.g. the dead toll in 2017 Portugal wildfires was of 66 people). The role of Mediterranean forests in global change mitigation through carbon sequestration and storage is also increasingly evaluated, and especially the dependence of this service on forest management practices (Koniak et al. 2011; Pardos et al. 2015; Bottalico et al. 2016).

We only found one study making future predictions of cultural services (Koniak et al. 2011). The small representation of studies evaluating the future of cultural services is a general pattern observed in other ES impact evaluations, with independence of the ecosystem/thematic scope (Martinez-Harms et al. 2015; Boerema et al. 2016; IPBES 2018a). This might be because the change of social values over time is very hard to quantify, model and predict (cultural services are most commonly evaluated through proxies Egoh et al. 2012; IPBES 2016), and it is generally easier to make predictions of indicators that depend on already observed environmental relationships (i.e. mathematical equations) such as forest growth and timber production. Given the difficulty of predicting social values and individual choices, future evaluations of cultural services might need to be indirectly inferred from changes in nature-based indicators. For example, the leisure use of Mediterranean pine forests (for walking, mountain biking, hunting, etc.) will probably be negatively affected by the increasing incidence of pest outbreaks of the processionary pine moth (*Thaumetopoea pityocampa*) favored by warmer winters (Battisti et al. 2005), as this species is responsible of strong allergic reactions in humans (Battisti et al. 2017). Although it is difficult to predict when, where and how these allergic symptoms will occur and how this will impact the leisure value of forest, it is possible to predict the vulnerability of forest to pest outbreaks given some knowledge about the ecology of the moth species and its relationship with environmental conditions, and indirectly infer where there could be potential conflicts with humans (e.g. peri-urban parks, national parks and other popular recreational areas). Therefore, the

future prediction of cultural services will require the integration of nature/biodiversity and ecosystem services models and indicators, currently poorly linked (IPBES 2016).

None of the studies selected modelled the demand side of the ecosystem services indicators. This might be explained by the fact that estimating and modelling services demands and flows is harder than estimating services production, since in today´s globalized word, the supply and demand of services often occur across different spatial and temporal scales (Burkhard et al. 2012). Despite some modelling tools already allow to quantify ecosystem services flows (e.g. the Artificial Intelligence for Ecosystem Services modelling tool-ARIES; Bagstad et al. 2013), the challenge remains to predict what the future demands will be using integrated socio-ecological approaches.

Regarding nature indicators, the strong bias observed towards the evaluation of species/populations distribution patterns might respond to the fast development of species distribution and population modelling techniques in the last two decades (Brotons 2014). Our results show that there is still considerable scope for research on other types of indicators that might be more informative about ecosystem function and dynamics (e.g. genetic composition, traits diversity; Pereira et al. 2013) and therefore, of the vulnerability of ecosystems to global change and their capacity to adapt and continue providing multiple ES and contributing to human wellbeing. Despite the increasing debate around the link between nature (biodiversity) indicators and the capacity of ecosystems to provide services (Cardinale et al. 2012; Ricketts et al. 2016), the presence of studies evaluating such relationship in the selected literature was negligible (as also found at the IPBES assessment on models and scenarios; IPBES 2016). This hampers our capacity to identify relationships between ecosystem thresholds and tipping points and their consequences for human well-being. Moreover, we show that the proportion of studies evaluating multiple indicators simultaneously is very low, making it difficult to assess trade-offs between biodiversity and ES indicators or among ES types (see also Boerema et al. 2016).

Further work regarding predictions of biodiversity and ecosystem services indicators should focus on assessing indicator trends as a function of the scenario assessed (drivers included, spatio-

temporal scales considered, etc.), as recently presented in the IPBES regional assessments (IPBES 2018b, a). Generally, this remains a challenge due to the lack of consensus on the use of indicators, the way the data is reported in studies (e.g. absolute value vs. % increments) and the difficulty of comparing indicators modelled under different global change assumptions (e.g. at different spatio-temporal scales).

5. Conclusions

Our literature review highlights several gaps in the way we conduct assessments of future changes in nature and ES provision in Mediterranean forests. There are various potential avenues to achieve higher levels of integration and realism when making future predictions of the state and dynamics of Mediterranean ecosystems under global change scenarios. In particular, future nature and ES research should focus future work on: (*i*) integrating multiple processes and driving forces operating at different spatio-temporal scales; (ii) considering the uncertainty around how these drivers will change in the future (by comparison of multiple scenarios), as well as any potential feedbacks between them; (*iii*) advancing on integrative approaches that consider the interdependencies between the different components of the socio-ecological systems (*iv*) developing models to assess a wider set of nature and ES indicators, so that trade-offs could be evaluated. There is no doubt of the important role that ecological models and scenarios play in achieving these goals. However, the art of predicting future condition of ecosystems is of little use if this information cannot be adequately incorporated into the decision-making policy cycle to contribute to sustainability goals. Therefore, and in parallel to the improvements in ecological models proposed above, future efforts should focus on strengthening the science-policy interface (one of the main goals of the IPBES) to allow the end-users of the tools and indicators (decision makers) into the framing of the questions tested by scientists/experts. Although we focused our review on Mediterranean forest systems, our results may be of wider implication for other similar regions and systems, keeping in mind that biases and constraints might be larger in many regions (e.g. regarding data and knowledge availability), and not easily solved by downscaling global change assessments to the region of interest.

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REFERENCES

Alcamo J, Ribeiro T (2001) Scenarios as tools for international environmental assessments. Experts' corner report Prospects and Scenarios No 5. European Environmental Agency. In: Eur. Environ. Agency. https://www.eea.europa.eu/publications/environmental_issue_report_2001_24

Bagstad KJ, Johnson GW, Voigt B, Villa F (2013) Spatial dynamics of ecosystem service flows: A comprehensive approach to quantifying actual services. Ecosyst Serv 4: 117–125. doi: 10.1016/j.ecoser.2012.07.012

Bai X, van der Leeuw S, O'Brien K, Berkhout F, Biermann F, Brondizio ES, Cudennec C, Dearing J, Duraiappah A, Glaser M, Revkin A, Steffen W, Syvitski J (2016) Plausible and desirable futures in the Anthropocene: A new research agenda. Glob Environ Chang 39: 351–362. doi: 10.1016/j.gloenvcha.2015.09.017

Battisti A, Larsson S, Roques A (2017) Processionary moths and associated urtication risk : global change – driven effects. Annu Rev Entomol 62: 323–342. doi: 10.1146/annurev-ento-031616-034918

Battisti A, Netherer S, Robinet C, Roques A (2005) Expansion of geographic range in the pine processionary moth caused by increased winter temperatures. Ecol Appl 15: 2084–2096. doi: 10.1890/04-1903

Boerema A, Rebelo AJ, Bodi MB, Esler KJ, Meire P (2016) Are ecosystem services adequately quantified? J Appl Ecol 54: 358–370. doi: 10.1111/1365-2664.12696

Bottalico, F, Pesola, L, Vizzarri, M, Antonello, L, Barbati, A, Chirici, G, Corona, P, Cullotta S, Garfì V, Giannico V, Lafortezza R, Lombardi F, Marchetti M, Nocentini S, Riccioli F, Travaglini D, Sallustio L (2016) Modeling the influence of alternative forest management scenarios on wood production and carbon storage: A case study in the Mediterranean region. Environ Res 144: 72-87. doi: 10.1016/j.envres.2015.10.025

Böttcher H, Verkerk PJ, Gusti M, Havlík P, Grassi G (2012) Projection of the future EU forest CO 2 sink as affected by recent bioenergy policies using two advanced forest management models. GCB Bioenergy 4: 773–783. doi: 10.1111/j.1757-1707.2011.01152.x

Brooks TM, Butchart SHM, Cox NA, Heath M, Craig H-T, Hoffmann M, Kingston N, Rodríguez JP, Stuart SN, Smart J (2015) Harnessing biodiversity and conservation knowledge products to

track the Aichi Targets and Sustainable Development Goals. Biodiversity 16: 157–174. doi: 10.1080/14888386.2015.1075903

Brotons L (2014) Species distribution models and impact factor growth in environmental journals: methodological fashion or the attraction of global change science. PLoS One 9:e111996. doi: 10.1371/journal.pone.0111996

Brotons L, Aquilué N, De Cáceres M, Fortin MJ, Fall A (2013) How fire history, fire suppression practices and climate change affect wildfire regimes in Mediterranean landscapes. PLOS one 8: p.e62392. doi: 10.1371/journal.pone.0062392

Burkhard B, Kroll F, Nedkov S, Müller F (2012) Mapping ecosystem service supply, demand and budgets. Ecol Indic 21: 17–29. doi: 10.1016/j.ecolind.2011.06.019

Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings S, Venail P, Narwani A, Mace GM, Tilman D, Wardle DA, Kinzig A, Daily GD, Loreau M, Grace JB, Larigauderie A, Srivastava DS, Shahid N (2012) Biodiversity loss and its impact on humanity. Nature 489: 326–326. doi: 10.1038/nature11148

Clark JS, Carpenter SR, Barber M, Collins S, Dobson A, Foley JA, Lodge DM, Pascual M, Pielke Jr R, Pizer W, Pringle C, Reid WV, Rose KA, Sala O, Schlesiger WH, Wall DH, Wear D (2001) Ecological Forecasts: An Emerging Imperative. Science 293:657–660. doi: 10.1126/science.293.5530.657

Convention on Biological Diversity (2015) Report of the ad hoc technical expert group on indicators for the strategic plan for biodiversity 2011-2020. https://www.cbd.int/doc/meetings/ind/id-ahteg-2015-01/official/id-ahteg-2015-01-03-en.pdf

Convention on Biological Diversity (2014) Global Biodiversity Outlook 4. https://www.cbd.int/gbo/gbo4/publication/gbo4-en-hr.pdf

Cuddington K, Fortin M-J, Gerber LR, Hastings A, Liebhold A, O´Connor M, Ray C (2013) Process-based models are required to manage ecological systems in a changing world. Ecosphere 4:1–12. doi: 10.1890/ES12-00178.1

Díaz S, Demissew S, Carabias J, Joly C, Lonsdale M, Ash N, Larigauderie A, Adhikari JR, Arico S, Báldi A, Bartuska A, Baste IA, Bilgin A, Brondizio E, Chan KMA, Figueroa VE, Duraiappah A, Fischer M, Hill R, Koetz T, Leadley P, Lyver P, Mace GM, Martin-Lopez B, Okumura M, Pacheco D, Pascual U, Pérez ES, Reyers B, Roth E, Saito O, Scholes RJ, Sharma N, Tallis H, Thaman R, Watson R, Yahara T, Hamid ZA, Akosim C, Al-Hafedh Y, Allahverdiyev R, Amankwah E, Asah ST, Asfaw Z, Bartus G, Brooks LA, Caillaux J, Dalle G, Darnaedi D, Driver A, Erpu G, Escobar-Eyzaguirre P, Failler P, Fouda AMM, Fu B, Gundimeda H, Hashimoto S, Homer F, Lavorel S, Lichtenstein G, Mala WA, Mandivenyi W, Matczak P, Mbizvo C, Mehrdadi M, Metzger JP, Mikissa JB, Moller H, Mooney HA, Mumby P, Nagendra H, Nesshover C, Oteng-Yeboah AA, Pataki G, Roué M, Rubis J, Schultz M, Smith P, Sumaila R, Takeuchi K, Thomas S, Verma M, Yeo-Chang Y, Zlatanova D (2015) The IPBES Conceptual Framework - connecting nature and people. Curr Opin Environ Sustain 14:1–16. doi: 10.1016/j.cosust.2014.11.002

Diffenbaugh NS, Giorgi F (2012) Climate change hotspots in the CMIP5 global climate model ensemble. Clim Change 114:813–822. doi: 10.1007/s10584-012-0570-x

Doblas-Miranda E, Martínez-Vilalta J, Lloret F, Álvarez A, Ávila A, Bonet FJ, Brotons L, Castro J, Curiel Yuste J, Díaz M, Ferrandis P, García-Hurtado E, Iriondo JM, Keenan TF, Latron J, Llusià J, Loepfe L, Mayol M, Moré G, Moya D, Peñuelas J, Pons X, Poyatos R, Sardand J, Sus O, Vallejo VR, Vayreda J, Retana J (2015) Reassessing global change research priorities in mediterranean

terrestrial ecosystems: How far have we come and where do we go from here? Glob Ecol Biogeogr 24:25–43. doi: 10.1111/geb.12224

EEA (2005) Vulnerability and adaptation to climate change in Europe. Technical Report No. 7. In: Eur. Environ. Agency. https://www.eea.europa.eu/publications/technical_report_2005_1207_144937

Egoh B, Drakou EG, Maes J, Willemen L (2012) Indicators for mapping ecosystem services : A review. In: JRC Sci. Policy Reports. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/indicators-mapping-ecosystem-services-review

FAO, Plan Bleu (2013) State of Mediterranean Forests 2013. http://www.fao.org/docrep/017/i3226e/i3226e.pdf

Fernandes PM, Barros AMG, Pinto A, Santos JA (2016) Characteristics and controls of extremely large wildfires in the western Mediterranean Basin. J Geophys Res Biogeosciences 121:2141–2157. doi: 10.1002/2016JG003389

Founda D, Giannakopoulos C (2009) The exceptionally hot summer of 2007 in Athens, Greece - A typical summer in the future climate? Glob Planet Change 67:227–236. doi: 10.1016/j.gloplacha.2009.03.013

FRB (2013) Scénarios de la biodiversité: un état des lieux des publications scientifiques françaises. http://www.fondationbiodiversite.fr/images/documents/Rapports_Etudes/ScenariosEtatLieux.pdf

García-Ruiz JM (2010) The effects of land uses on soil erosion in Spain: A review. Catena 81:1–11. doi: 10.1016/j.catena.2010.01.001

Gauquelin T, Michon G, Joffre R, R, Duponnois R, Génin D, Fady B, Dagher-Kharrat MB, Derrigj A, Slimani S, Badri W, Alidriqui M, Auclair L, Simenel R, Aderghal M, Baudoin E, Galiana A, Prin Y, Sanguin H, Fernandez C, Baldy V (2018) Mediterranean forests, land use and climate change: a social-ecological perspective. Reg Environ Chang 18:623–636. doi: 10.1007/s10113-016-0994-3

Geijzendorffer IR, Cohen-Shacham E, Cord AF, Cramer W, Guerra C, Martín-López B (2017) Ecosystem services in global sustainability policies. Environ Sci Policy 74:40–48. doi: 10.1016/j.envsci.2017.04.017

Gil-Tena A, Aquilué N, Duane A, De Cáceres M, Brotons L (2016) Mediterranean fire regime effects on pine-oak forest landscape mosaics under global change in NE Spain. Eur J For Res 135:403-416. doi: 10.1007/s10342-016-0943-1

Górriz-Mifsud E, Varela E, Piqué M, Prokofieva I (2016) Demand and supply of ecosystem services in a Mediterranean forest: Computing payment boundaries. Ecosyst Serv 17:53–63. doi: 10.1016/j.ecoser.2015.11.006

Harfoot M, Tittensor DP, Newbold T, McInerny G, Smith MJ, Schalemann JPW (2014) Integrated assessment models for ecologists: The present and the future. Glob Ecol Biogeogr 23:124–143. doi: 10.1111/geb.12100

Harrison PA, Dunford RW, Holman IP, Rounsevell MDA (2016) Climate change impact modelling needs to include cross-sectoral interactions. Nat Clim Chang 6:885–890. doi: 10.1038/nclimate3039

Hauck J, Winkler KJ, Priess JA (2015) Reviewing drivers of ecosystem change as input for environmental and ecosystem services modelling. Sustain Water Qual Ecol 5:9–30. doi: 10.1016/j.swaqe.2015.01.003

IPBES (2018a) Regional assessment Report on Biodiversity and Ecosystem Services for Europe and Central Asia. IPBES/6/INF/6/Rev.1. https://www.ipbes.net/assessment-reports/eca

IPBES (2016) Scenarios and Models of Biodiversity and Ecosystem Services. https://www.ipbes.net/assessment-reports/scenarios

IPBES (2018b) Regional assessment Report on Biodiversity and Ecosystem Services for Africa. IPBES/6/INF/3/Rev.1. https://www.ipbes.net/assessment-reports/africa

Keeley JE, Bond WJ, Bradstock RA, Pausas JG, Rundel PW (2012) Fire in Mediterranean ecosystems: ecology, evolution and management. Cambridge University Press, New York, USA

Kelly RA. B, Jakeman AJ., Barreteau O, Brosuk ME, Sondoss E, Hamilton SH, Henriksen HJ, kuikka S, Maier HR, Rizzoli AE, van Delden H, Voinov AA (2013) Selecting among five common modelling approaches for integrated environmental assessment and management. Environ Model Softw 47:159–181. doi: 10.1016/j.envsoft.2013.05.005

Kok K, Bärlund I, Flörke M, Holman I, Gramberger, Sendzimir, Stuch B, Zellmer K (2015) European participatory scenario development: strengthening the link between stories and models. Clim Change 128:187–200. doi: 10.1007/s10584-014-1143-y

Kok MTJ, Kok K, Peterson GD, Hill R, Agard J, Carpenter SR (2017) Biodiversity and ecosystem services require IPBES to take novel approach to scenarios. Sustain Sci 12:177–181. doi: 10.1007/s11625-016-0354-8

Koniak G, Noy-Meir I, Perevolotsky A (2011) Modelling dynamics of ecosystem services basket in Mediterranean landscapes: A tool for rational management. Landsc Ecol 26:109–124. doi: 10.1007/s10980-010-9540-8

Korzukhin MD, Ter-Mikaelian MT, Wagner RG (1996) Process versus empirical models: which approach for forest management? Can J For Res 26:879–887. doi: 10.1139/x26-096

Kraxner F, Nordström EM, Havlík P, Gusti M, Mosnier A, Frank S, Valin H, Fritz S, Fuss S, Kindermann G, McCallum I, Khabarov N, Böttcher H, See L, Aoki K, Schmid E, Máthé L, Oberstiner M (2013) Global bioenergy scenarios - Future forest development, land-use implications, and trade-offs. Biomass and Bioenergy 57:86–96. doi: 10.1016/j.biombioe.2013.02.003

Lavorel S, Bayer A, Bondeau A, Lautenbach S, Ruiz-Frau A, Schulp N, Seppelt R, Verburg P, van Teeffelen A, Vannier C, Arneth A, Cramer W, Marba N (2017) Pathways to bridge the biophysical realism gap in ecosystem services mapping approaches. Ecol Indic 74:241–260. doi: 10.1016/j.ecolind.2016.11.015

Mahmoud M, Liu Y, Hartmann H, Stewart S, Wagener T, Semmens D, Stewart R, Gupta H, Dominguez D, Dominguez F, Hulse D, Letcher R, Rashleigh B, Smith C, Street R, Ticehurst J, Twery M, van Delden H, Waldick R, White D, Winter L (2009) A formal framework for scenario development in support of environmental decision-making. Environ Model Softw 24:798–808. doi: 10.1016/j.envsoft.2008.11.010

Malek Ž, Verburg P (2017) Mediterranean land systems: Representing diversity and intensity of complex land systems in a dynamic region. Landsc Urban Plan 165:102–116. doi: 10.1016/j.landurbplan.2017.05.012

Malek Ž, Verburg PH, Geijzendor IR, Bondeau A, Cramer W (2018) Global change effects on land management in the Mediterranean region. Glob Environ Chang 50:238–254. doi: 10.1016/j.gloenvcha.2018.04.007

Martinez-Harms MJ, Bryan BA, Balvanera P, Law EA, Rhodes JR, Possingham HP, Wilson KA (2015) Making decisions for managing ecosystem services. Biol Conserv 184:229–238. doi: 10.1016/j.biocon.2015.01.024

Martínez-Vilalta J, Lloret F (2016) Drought-induced vegetation shifts in terrestrial ecosystems: The key role of regeneration dynamics. Glob Planet Change 144:94–108. doi: 10.1016/j.gloplacha.2016.07.009

McCarthy JJ, Canziani OF, Leary N, Dokken DJ, White KS (2011) Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK

MEA (2005) Ecosystems and Human Well-Being: Synthesis. https://www.millenniumassessment.org/documents/document.356.aspx.pdf

Morán-Ordóñez A, Briscoe NJ, Wintle BA (2018) Modelling species responses to extreme weather provides new insights into constraints on range and likely climate change impacts for Australian mammals. Ecography (Cop) 41:308–320. doi: 10.1111/ecog.02850

Moss RH, Edmonds J a, Hibbard KA, Manning MR, Rose SK, van Vuuren DP, Carter TR, Emori S, Kainuma M, Kram T, Meehl G, Mitchell JFB, Nakicenovic N, Riahi k, Smith SJ, Stouffer RJ, Thomson AM, Weyant JP, Wibanks TJ (2010) The next generation of scenarios for climate change research and assessment. Nature 463:747–756. doi: 10.1038/nature08823

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403:853–858. doi: 10.1038/35002501

Nakicenovic N, Alcamo J, Grubler A, Riahi K, Roehrl RA, Rogner H-H, Victor N (2000) Special Report on Emission Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. https://ipcc.ch/pdf/special-reports/spm/sres-en.pdf

Nocentini S, Coll L (2013) Mediterranean forests: human use and complex adaptive systems. In: Messier C, Puettmann KJ, Coates KD (eds) Managing Forests as complex adaptive systems. Building resilience to the challenge of global change. The Earthscan Forest Library (series)., Routledge, NY, USA

O´Neill BC, Kriegler E, Ebi KL, Kemp-Benedict E, Riahi K, Rothman DS, van Ruijven BJ, van Vuuren DP, Birkmann J, Kok K, Levy M, Solecki W (2015) The Roads Ahead : Narratives for Shared Socioeconomic Pathways describing World Futures in the 21 st Century. Glob Environ Chang 42:169–180. doi: 10.1016/j.gloenvcha.2015.01.004

Pacheco FAL, Santos RMB, Sanches Fernandes LF, Pereira MG, Cortes RM (2015) Controls and forecasts of nitrate yields in forested watersheds: A view over mainland Portugal. Sci Total Environ 537:421–440. doi: 10.1016/j.scitotenv.2015.07.127

Palahi M, Mavsar R, Gracia C, Birot Y (2008) Mediterranean forests under focus. Int For Rev 10:676–688. doi: 10.1505/ifor.10.4.676

Pardos M, Calama R, Maroschek M, Rammer W, Lexer MJ (2015) A model-based analysis of climate change vulnerability of Pinus pinea stands under multiobjective management in the Northern Plateau of Spain. Ann For Sci 72:1009–1021. doi: 10.1007/s13595-015-0520-7

Pausas JG (2006) Simulating Mediterranean landscape pattern and vegetation dynamics under different fire regimes. Plant Ecol 187:249–259. doi: 10.1007/s11258-006-9138-z

Pausas JG, Lloret F (2007) Spatial and temporal patterns of plant functional types under simulated fire regimes. Int J Wildl Fire 16:484–492. doi: 10.1071/WF06109

Pecl GT, Araújo MB, Bell JD, Blanchard J, Bonebrake RC, Chen i-C, Clark TC, Colwell RK, Danielsen F, Evengård B, Falconi L, Ferrier S, Frusher S, Garcia RA, Griffis RB, Hobday AJ, Janion-Scheepers C, Jarzyna MA, Jennings S, Lenoir J, Linnetved HI, Martin VY, McCormack PC, McDonald J, Mitchell NJ, Mustonen, T, Pandolfi JM, Pettorelli N, Popova E, Robinson SA, Scheffers BR, Shaw JD, Sorte CJ, Strugnell JM, Sunday JM, Tuanmu M-N, verges A, Villanueva C, Wernberg T, Wapstra E, Willians SE (2017) Biodiversity redistribution under climate change: impacts on ecosystems and human well-being. Science 355: eaai9214. doi: 10.1126/science.aai9214

Peñuelas J, Sardans J, Filella I, Estiarte M, Llusià J, Ogaya R, Carnicer J, Bartrons M, Rivas-Ubach A, Grau O, Pequero G, Margalef O, Pla-Rabés S, Stefanescu C, Asensio D, Preece C, Lui L, Verger A, Barbeta A, Achotegui-Castells A, Gargallo-Garriga A, Sperlich D, Farré-Armengol G, Fernández-Martínex M, Liu D, Zhang C, Urbina I, Camino-Serrano M, Vives-Ingla M, Stocker BD, Balzarolo M, Guerrierei R, Paucelle M, Marañón-Jiménez S, Bórnez-Mejías K, Zhaobin Mu, Descals A, Castellanos A, Terradas J (2017) Impacts of global change on Mediterranean forests and their services. Forests 8:1–37. doi: 10.3390/f8120463

Pereira HM, Ferrier S, Walters M, Geller GN, Jongman RHG, Scholes RJ, Bruford MW, Brummitt N, Butchart SHM, Cardoso AC, Coops NC, Dullo E, Faith DP, Freyhof J, Gregory RD, Heop C, Höft R, Hurtt G, Jetz W, Karp DS, McGeoch Ma, Obura D, Onoda Y, Pettorelli N, Reyers B, Sayre R, Scharlemann JPW, Stuart SN, Turak E, Warpole M, Wegmann M (2013) Essential Biodiversity Variables. Science (80-) 339:277–278. doi: 10.1126/science.1229931

Peterson GD, Cumming GS, Carpenter SR (2003) Scenario planning: a tool for conservation in an uncertain world. Conserv Biol 17:358–366. doi: 10.1046/j.1523-1739.2003.01491.x

Resco De Dios V, Fischer C, Colinas C (2007) Climate change effects on mediterranean forests and preventive measures. New For 33:29–40. doi: 10.1007/s11056-006-9011-x

Ricketts TH, Watson KB, Koh I, Ellis AM, Nicholson CC, Posner S, Richardson LL, Sonter LJ (2016) Disaggregating the evidence linking biodiversity and ecosystem services. Nat Commun 7:13106. doi: 10.1038/ncomms13106

Rieb JT, Chaplin-Kramer R, Daily GC, Armsworth PR, Böhning-Gaese K, Bonn A, Cumming GS, Eigenbrod F, Grimm V, Jackson BM, Marques A, Pattanayak SK, Pereira HM, Peterson GD, Ricketts TH, Robinson BE, Schröter M, Schulte LA, Seppelt R, Turner MG, Bennett EM (2017) When, Where, and How Nature Matters for Ecosystem Services: Challenges for the Next Generation of Ecosystem Service Models. Bioscience 67:820–833. doi: 10.1093/biosci/bix075

Rosa IM, Pereira HM, Ferrier S, Alkemade R, Acosta La, Akcakaya HR, den Belder E, Fazel AM, Fujimori S, Harfoot M, Harhash KA, Harrison PA, Hauck J, Hendriks RJJ, Hernández G, Jetz W, Karlsson-Vinkhuyzen SI, Kim H, King N, Kok MTJ, Kolomytsev GO, Lazarova T, Leadley O, Lundquist CJ, García Márquez J, Meyer C, Navarro LM, Nesshöver C, Ngo HT, Ninan KN, Palomo MG, Pereira LM, Peterson GD, Pichs R, Popp A, Purvis A, Ravera F, Rondinini C, Sathyapalan J, Schipper AM, Seppelt R, Settele J, Sitas N, van Vuuren D (2017) Multiscale scenarios for nature futures. Nat Ecol Evol 1:1416–1419. doi: 10.1038/s41559-017-0273-9

Ruffault J, Curt T, StPaul NM, Moron V, Trigo RM (2018) Extreme wildfire events are linked to global-change-type droughts in the northern Mediterranean. Nat Hazards Earth Syst Sci 18:847–856. doi: 10.5194/nhess-18-847-2018

Seidl R, Fernandes PM, Fonseca TF, Guillet F, Jönsson AM, Marganicova K, Netherer S, Arpaci A, Bontemps JD, Bugmann H, González-Olabarría JR, Lasch P, Meredieu C, Moreira F, Schelhaas M-J, Mohren F (2011) Modelling natural disturbances in forest ecosystems: A review. Ecol Modell 222:903–924. doi: 10.1016/j.ecolmodel.2010.09.040

Seidl R, Schelhaas M-J, Rammer W, Verkerk PJ (2014) Increasing forest disturbances in Europe and their impact on carbon storage. Nat Clim Chang 4:806–810. doi: 10.1038/nclimate2318

Sirami C, Caplat P, Popy S, Clamens A, Arlettaz R, Jiguet F, Brotons L, Martin J-L (2017) Impacts of global change on species distributions: obstacles and solutions to integrate climate and land use. Glob Ecol Biogeogr 26:385–394. doi: 10.1111/geb.12555

Stocker TF, Qin D, Plattner G-K, Tignor MMB, Allen SK, Bochung J, Nauels A, Xia Y, Bex V, Midgley PM (2013) Climate Change 2013 - The Physical Science Basis. In: Intergov. Panel Clim. Chang. http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SummaryVolume_FINAL.pdf

Talluto M V., Boulangeat I, Ameztegui A, Aubin I, Berteaux D, Butler A, Doyon F, Drever CR, Fortin M-J, Franceschini T, Liénard J, McKenney D, Solarik KA, Strigul N, Thuiller W, Gravel D (2016) Cross-scale integration of knowledge for predicting species ranges: A metamodelling framework. Glob Ecol Biogeogr 25:238–249. doi: 10.1111/geb.12395

Titeux N, Henle K, Mihoub J-B, Geijzendorffer Ir, Cramer W, Verburg PH, Brotons L(2016) Biodiversity scenarios neglect future land use change. Glob Chang Biol 1–11. doi: 10.1111/gcb.13272

van Vuuren DP, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard K, Hurtt GC, Kram T, Krey V, Lamarque J-F, Masui T, Meinshausen M,Nakicenovic N, Smith SJ, Rose SK (2011) The representative concentration pathways: An overview. Clim Change 109:5–31. doi: 10.1007/s10584-011-0148-z

Vihervaara P, Rönkä M, Walls M (2010) Trends in ecosystem service research: Early steps and current drivers. Ambio 39:314–324. doi: 10.1007/s13280-010-0048-x

Query	Field	Parameters	Motivation
1	Year	1990-2016	Restricts the time period of the results to the last 25 years. It captures the increasing use of scenarios in Ecology since the publication of the first IPCC assessment report in 1990 (Moss et al. 2010)
2	Topic	(((model* OR project* OR predict* OR simulat*) AND future) OR (scenari* OR forecast* OR foresight* OR storyline*))	Captures modelling studies addressing predictions into the future
3	Topic	(Mediterranean OR Gibraltar OR Portugal OR Spain OR France OR Monaco OR Italy OR Malta OR Slovenia OR Croatia OR Bosnia OR Montenegro OR Albania OR Greece OR Turkey OR Cyprus OR Syria OR Lebanon OR Israel OR Palestine OR Egypt OR Libya OR Tunisia OR Algeria OR Morocco OR Iberia* OR Balkan* OR Anatolia)	Sets the geographic context: the Mediterranean basin and all the countries within it
4	Topic	(forest* OR woodland*)	Identifies studies focusing on forest or woodlands as their subject study system

We use the boolean operator 'AND' to combine the different queries. We refined the results using "Articles' as *Document type*, 'English' as Language' and 'Forestry', 'Plant Sciences', 'Environmental Sciences Ecology' or 'Biodiversity Conservation' as *Web of Science Subject categories*. The databases accessible to us in the Web of Science were CABI, SCIELO, WOS (Web of Science Core Collection) and CCC (Current Contents Connect). We selected the set of queries and keywords shown here after an initial scoping literature search phase in which we also included an additional query (5#) accounting for terms related to biodiversity, ecosystems and ES indicators (e.g. 'biodiversity OR ecosystem* OR "ecosystem* function*" OR "biological diversity" OR species OR "ecosystem service*" OR habitat* OR trait* OR vegetation* OR gene* OR landscape* OR biomass OR timber OR wood OR carbon OR erosion OR *water* OR recreat* OR regulat* OR game* OR 'non-wood forest products' OR 'Mushroom*' OR 'nutrient*' OR '*fire*); however, we observed that by adding this query we were leaving out many articles that were relevant for this review (because of terminological issues, eg many studies evaluate forest productivity using net primary production as indicator instead of wood biomass or timber production) and therefore, we chose to retain only the queries 1-4 that are more general.

Table 1. Search terms used for the literature review. The search was made on June 2016 on the complete range of references available at the Web of Science at that time.

Study area location and original extent of the article	• **Global/EU wide**: studies using models and scenario predictions for the global or Pan-European scales, from which we could extract results for the Mediterranean basin systems. • **Regional** (Pan-Mediterranean): predictions specifically designed for the Mediterranean region including case studies in two or more countries in the Mediterranean basin. • **National** (e.g. France) • **Subnational** (extent equivalent to level 2 of the NUTS 2013 classification of European regions available from the Eurostats web: http://ec.europa.eu/eurostat/web/nuts/; e.g. Provence-Alpes-Côte d'Azur) • **Local** (e.g. catchment A, municipality B)
Modelling approach used	• **Correlative/regression**: models assessing statistical relationships, whether causal or not, between two or more variables • **Mechanistic/Process-based or integrated approaches**: mechanistic models are based on a theoretical understanding of relevant ecological processes that are explicitly incorporated in the model. On the other hand, integrated approaches combine multiple model types, processes and/or components of the system modelled in a unique framework (Kelly et al. 2013)
Scenario type	• **Already published** (e.g. the latest greenhouse concentration scenarios adopted by the fifth IPCC Assessment Report: the representative concentration pathways; van Vuuren et al. 2011) • **User made**: scenarios made in the context of the article (e.g. through stakeholder/expert consultation or as a way of hypothesis testing) • **Mixed**: approaches combining already published scenarios with user made assumptions.
Scenario drivers	• **Number of drivers** (understood as values of environmental/social conditions that change over the time horizon of the projection and that are used to make predictions of models) • **Driver type:** climate, forest management, fire, land-use, water-use, pollution, grazing levels, etc.
Nature and/or ecosystem service indicator	• **Nature indicators** include measures of species/ecosystem distribution extent, species abundances or ecosystem structure/function. • **Ecosystem services** indicators (ES) were classified into 'provisioning', 'regulating & maintenance' or 'cultural' services following the Common International Classification of Ecosystem Services (CICES V4.3; www.cices.eu). We also evaluated fire risk as an ES indicator due to its importance in Mediterranean forests to regulate and maintain other ecosystem functions and processes (therefore included within the category 'regulating and maintenance').

Table 2. Information extracted from the selected articles. The right-hand column lists in detail the different categories into which we classified each study within each information field.

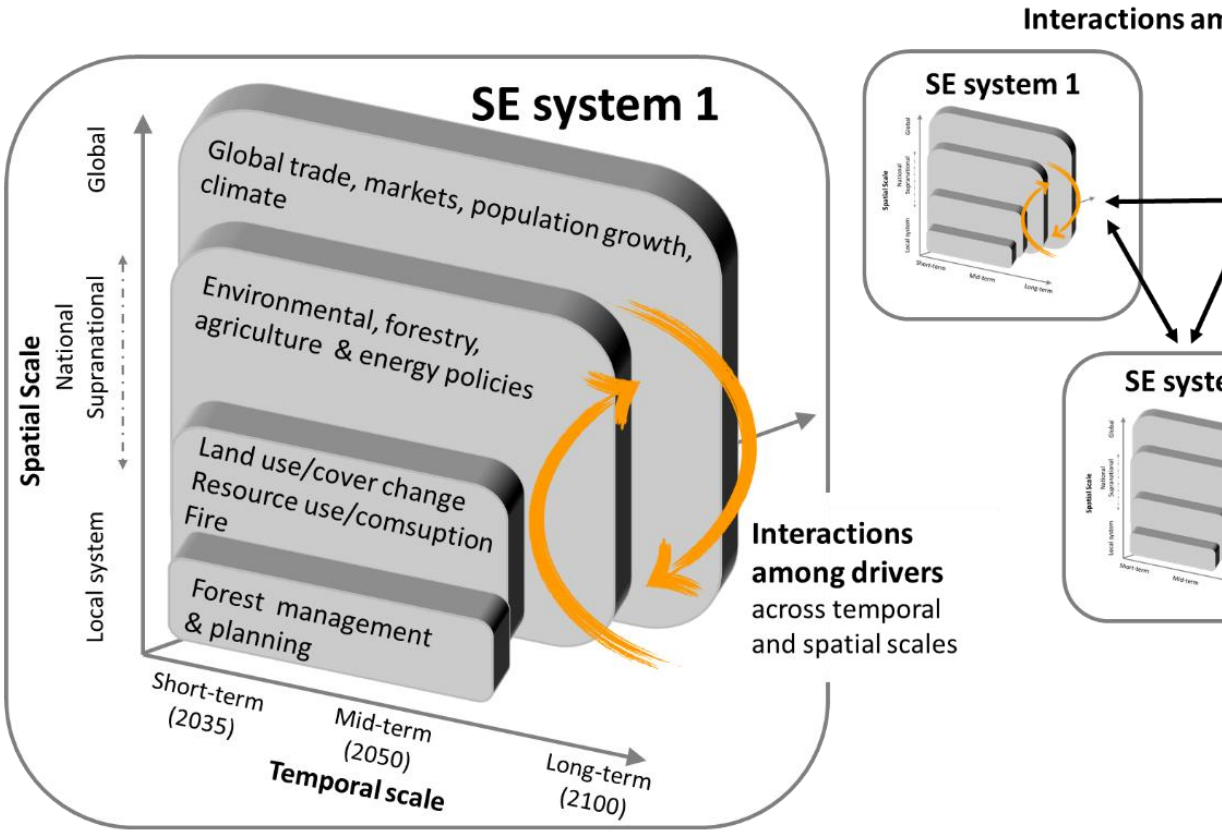


Figure 1. Diagram of potential levels of integration in biodiversity/nature and ecosystem services future impact assessm system (e.g. Mediterranean forests, SE system 1 box on the left side of the figure), scenarios and models should, to the both indirect and direct drivers of global change operating at multiple spatio-temporal scales, as well as for the interacti arrows). Ideally, SE systems should not be evaluated in isolation, but rather considering their interactions with other so also be interpreted as interactions between multiple sectors, such as forestry, agriculture, water management, conservati represented with the interaction between SE systems 1, 2 and 3). In the example of the SE system 1 box, the distributio reflects the temporal scale at which they are expected to exert a stronger impact on ecological processes operating in M implementation of environmental policies generally have an impact in the system at the mid-, long- term, changes in la system in the short-term). On the other hand, the Y-dimension of the rectangles reflects the spatial scale at which drive an influence from global to local environmental conditions, fires or forest management have a more localized impact).

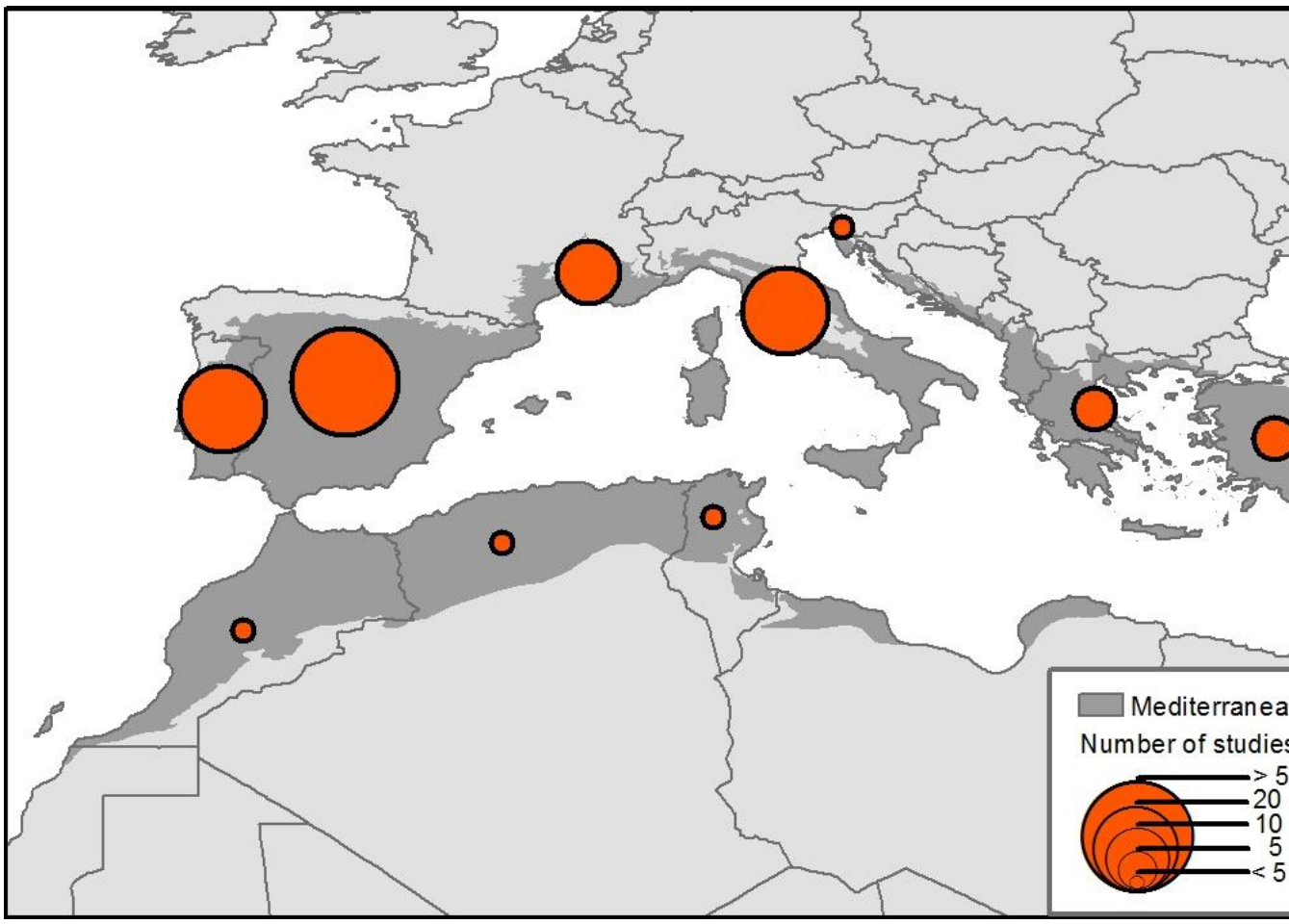


Figure 2. Geographical distribution of 133 national, sub-national and local studies assessed in this review. Note: the cir
not the exact location where the study was carried out. The extent of the Mediterranean domain (shaded in dark grey in
European Environmental Agency (layer of biogeographical regions: https://www.eea.europa.eu/data-and-maps/data/bio
WWF (layer of Terrestial Ecoregions of the World: https://www.worldwildlife.org/publications/terrestrial-ecoregions-o
for correlations between the number of studies in each country and different socio-economic indicators.

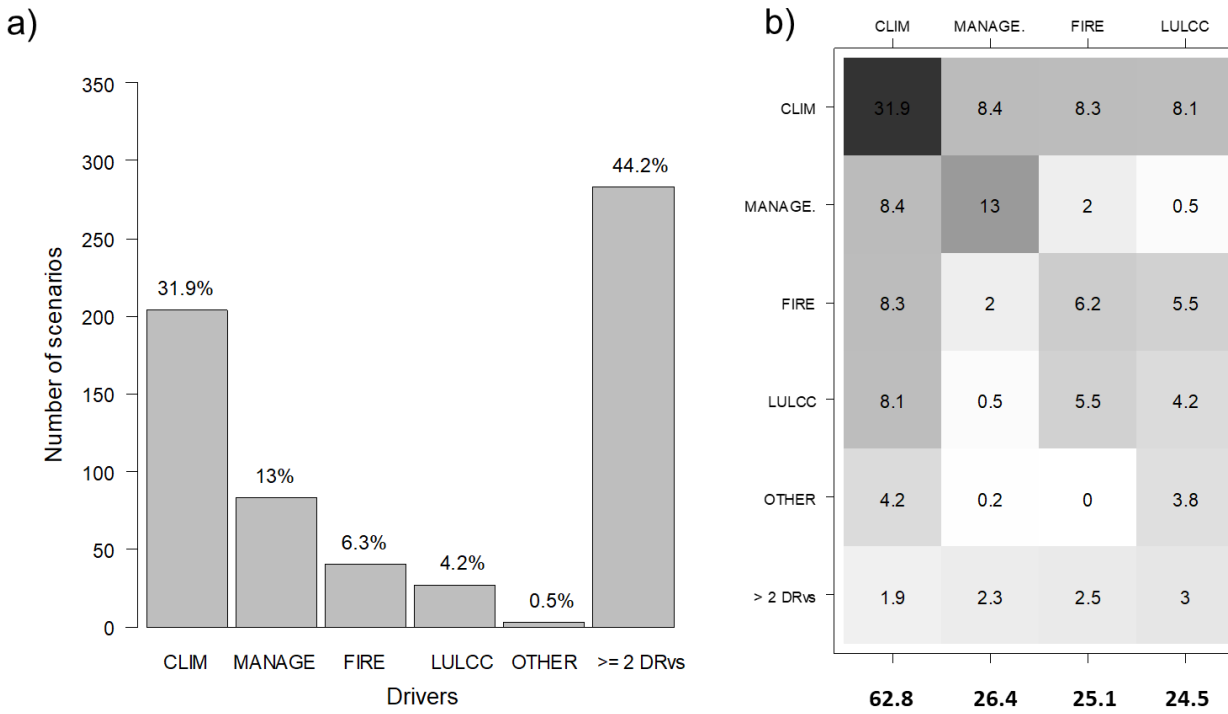
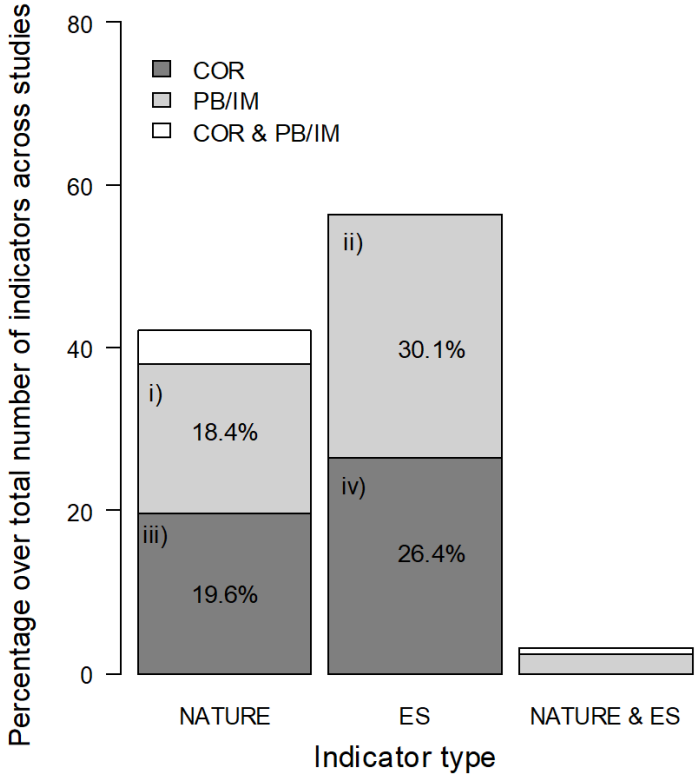


Figure 3. Driver types and driver combinations used in the scenarios found in the literature review. **a)** Each bar represe
single driver (X-axis: climate [CLIM], fire, land use land cover change [LULCC], management practices [MANAGE.],
species) or two drivers or more jointly (≥ 2 DRvs). The prevalence of the use of each of these drivers within the selecte
the top of each bar (e.g. climate bar: 31.9 % of the scenarios used climate as the only driver of system change); **b)** Preva
scenarios found in the selected literature. The most frequent combination of drivers is represented by darker gray tones
MANAG), whereas lighter squares indicate less frequent driver combinations (e.g. LULCC with MANAGE.). Values v
indicate percentages over the total number of scenarios in our database. Values in the diagonal of the heat map represen
(same values than in panel a). Values at the bottom of the heat map represent total use of a given driver (read from the t
other drivers (read from the left axis) in the scenarios of the selected articles (e.g. CLIM is considered as a driver of for
scenarios – 31.9% as solo-driver and 20.9% of the times in combination with other drivers-, whereas FIRE is used only
the values are symmetrical at both sides of the diagonal.

a)



b)

Count	Dri
i) NATURE PB/IM	
1	73.
2	16.
≥3	1(
ii) ES PB/IM	
1	57.
2	40.
≥3	2.(
iii) NATURE COR	
1	90.
2	9.4
≥3	
iv) ES COR	
1	83.
2	16.
≥3	

Figure 4. a) Prevalence in the selected literature of studies assessing ecosystem services indicators (ES), nature indica indicators in the same study (NATURE & ES). Different grey tones indicate different modelling approaches: dark grey approaches (COR), light grey for articles using process-based or integrated modelling approaches (PB/IM) and white fo IM in the same study (COR & PB/IM). **b)** For each of the dominant indicator-modelling approach combinations in plot PB/IM, iii) NATURE-COR and iv) ES-COR– we detail the frequency (from column 'count') of use of single-driver vs frequency of single-indicator vs multiple-indicator evaluations.

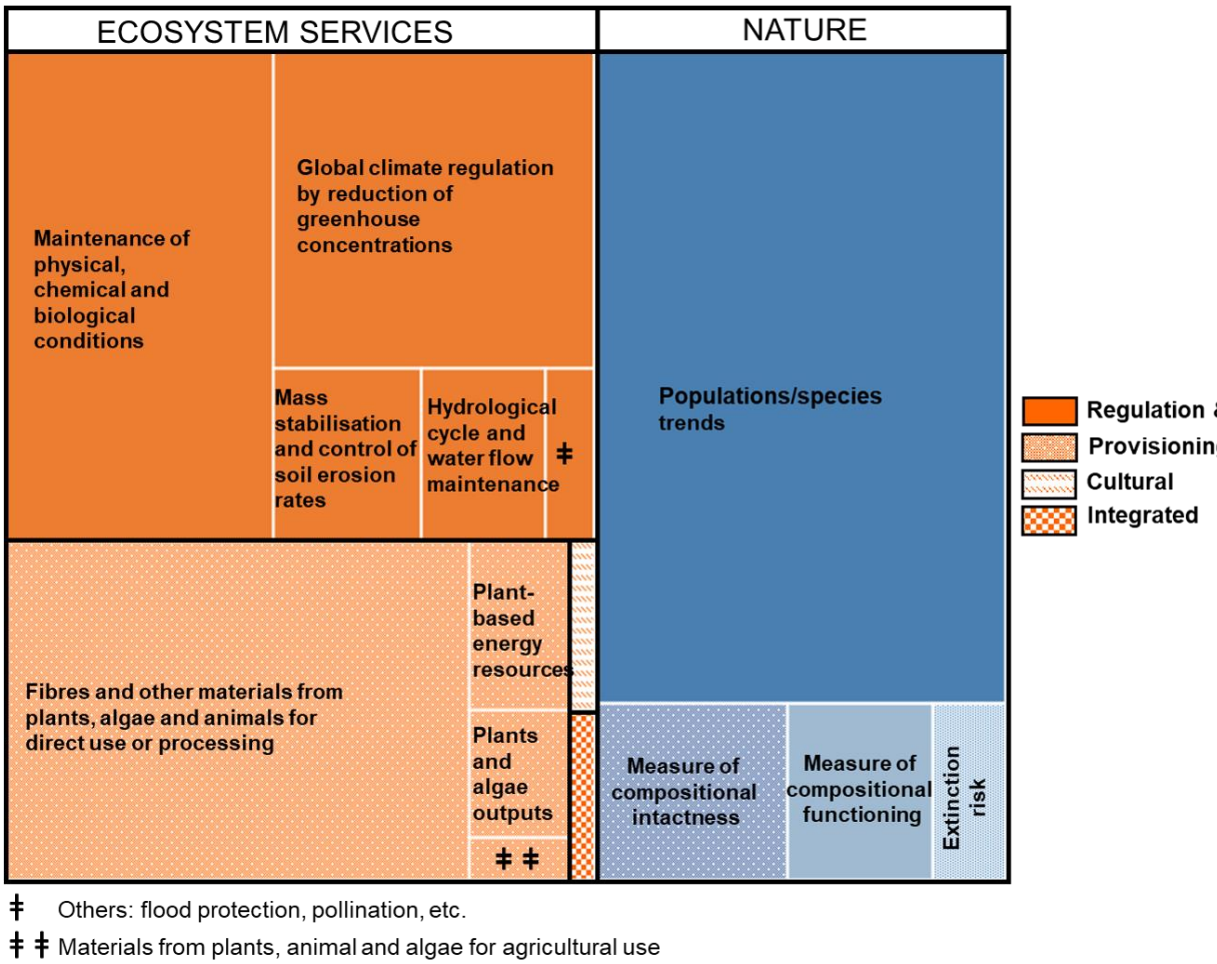


Figure 5. Types of indicators found in the literature search and their prevalence in the data set. Orange sections of the service indicators: provisioning, regulating, cultural services or integrative (multi-service indicators). Blue shaded secti indicators that we classified in four main groups: measures of extinction risk (e.g. viability of populations), indicators o expansion/contraction), measures of ecosystem functioning (e.g. trait diversity) and measures of compositional intactne The size of each box indicates the prevalence of each indicator type in the selected literature (ecosystem service classes Classification of Ecosystem Services - CICES V4.3; www.cices.eu).

The use of scenarios and models to evaluate the future of nature values and ecosystem services in Mediterranean forests

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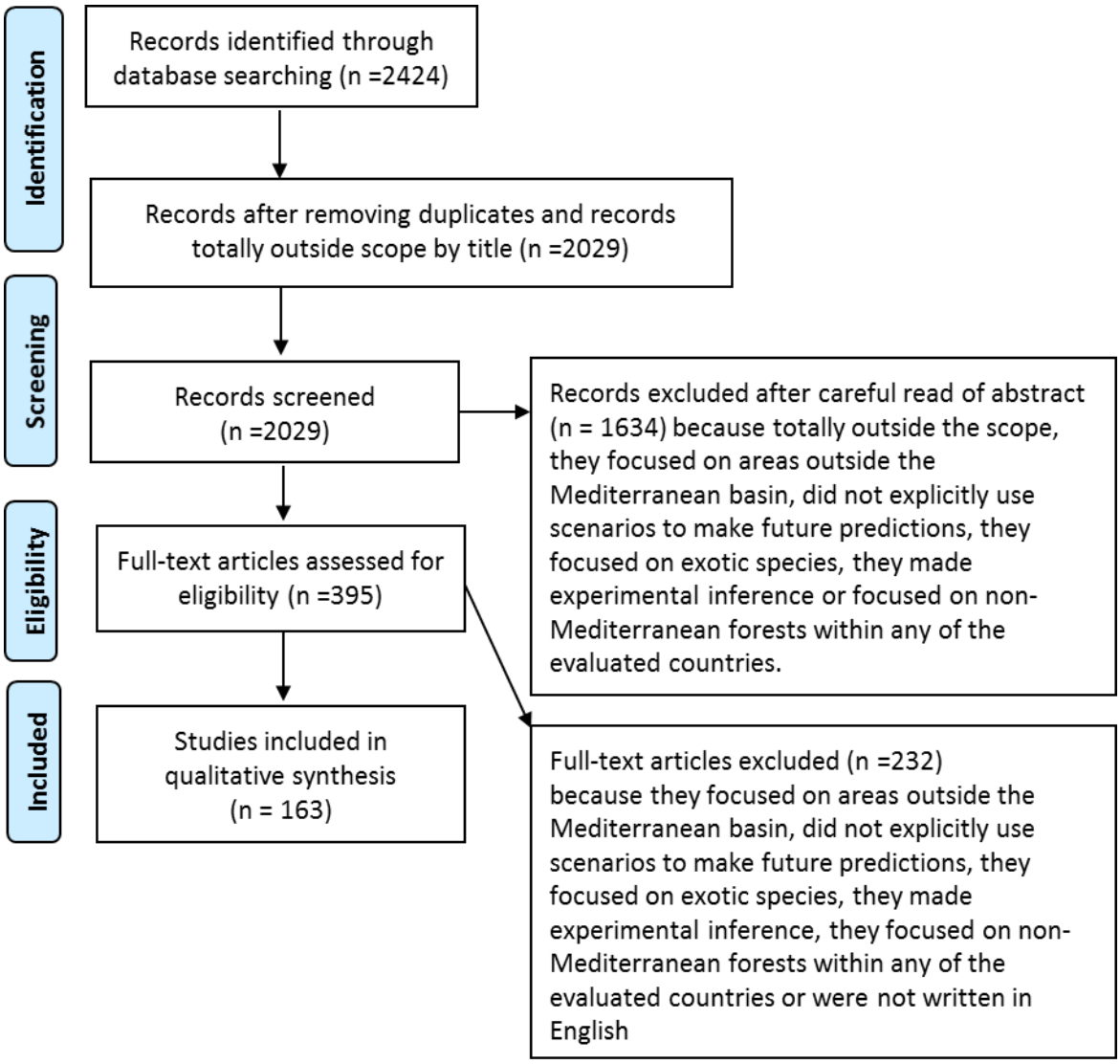
ELECTRONIC SUPPLEMENTARY MATERIAL for Regional Environmental Change

Online resource 1: Details of literature review

Flow chart based on PRISMA protocols (Moher et al. 2009) illustrating how papers were selected or discarded



Moher D, Liberati A, Tetzlaff J, Altman DG, The PG (2009) Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6: e1000097.

Online resource 2: List of publications included in the review.

See summary of the journals included in the review at the end of this list.

1. Ágreda T, Águeda B, Olano JM, Vicente-Serrano SM, Fernández-Toirán M (2015) Increased evapotranspiration demand in a Mediterranean climate might cause a decline in fungal yields under global warming. Glob Change Biol 21: 3499-3510. doi: 10.1111/gcb.12960
2. Alados CL, Pueyo Y, Escós J, Andujar A (2009) Effects of the spatial pattern of disturbance on the patch-occupancy dynamics of juniper–pine open woodland. Ecol Model 220: 1544-1550. doi: 10.1016/j.ecolmodel.2009.03.029
3. Alba-Sánchez F, López-Sáez JA, Nieto-Lugilde D, Svenning JC (2015) Long-term climate forcings to assess vulnerability in North Africa dry argan woodlands. Appl Veg Sci 18: 283-296. doi: 10.1111/avsc.12133
4. Alegria C, Tomé M (2013) A tree distance-dependent growth and yield model for naturally regenerated pure uneven-aged maritime pine stands in central inland of Portugal. Ann For Sci 70: 261-276. doi: 10.1007/s13595-012-0262-8
5. Alkemade R, Bakkenes M, Eickhout B (2011) Towards a general relationship between climate change and biodiversity: an example for plant species in Europe. Reg Environ Change 11: 143-150. doi: 10.1007/s10113-010-0161-1
6. Alonso R, Vivanco MG, González-Fernández I, Bermejo V, Palomino I, Garrido JL, Elvira S, Salvador P, Artíñano B (2011) Modelling the influence of peri-urban trees in the air quality of Madrid region (Spain). Environ Pollut 159: 2138-2147. doi: 10.1016/j.envpol.2010.12.005.
7. Amatulli G, Camia A, San-Miguel-Ayanz J (2013) Estimating future burned areas under changing climate in the EU-Mediterranean countries. Sci Total Environ 450: 209-222. doi: 10.1016/j.scitotenv.2013.02.014.
8. Anaya-Romero M, Abd-Elmabod SK, Muñoz-Rojas M, Castellano G, Ceacero CJ, Alvarez S, Méndez M, De la Rosa D (2015) Evaluating soil threats under climate change scenarios in the Andalusia Region, Southern Spain. Land Degrad Dev 26: 441-449. doi: 10.1002/ldr.2363
9. Anttila P, Asikainen A, Laitila J, Broto M, Campanero I, Lizarralde I, Rodríguez F (2011) Potential and supply costs of wood chips from forests in Soria, Spain. For Syst 20: 245-254. doi: 10.5424/fs/2011202-10363
10. Aparício S, Carvalhais N, Seixas J (2015) Climate change impacts on the vegetation carbon cycle of the Iberian Peninsula—Intercomparison of CMIP5 results. Biogeosciences 120: 641-660. doi: 10.1002/2014JG002755
11. Attorre F, Alfò M, De Sanctis M, Francesconi F, Valenti R, Vitale M, Bruno F (2011) Evaluating the effects of climate change on tree species abundance and distribution in the Italian peninsula. Appl Veg Sci 14:242-255. doi: 10.1111/j.1654-109X.2010.01114.x
12. Attorre F, Francesconi F, Scarnati L, De Sanctis M, Alfò, M, Bruno, F (2008) Predicting the effect of climate change on tree species abundance and distribution at a regional scale. iForest 1 :132-139. doi: 10.3832/ifor0467-0010132
13. Baltas EA, Karaliolidou MC (2008) Hydrological effects of land use and climate changes in northern Greece. Journal of Land Use Science 2: 225-24 doi: 10.1080/17474230701622908
14. Barbet-Massin M, Jiguet F (2011) Back from a predicted climatic extinction of an island endemic: a future for the Corsican Nuthatch. Plos One 6: p.e18228. doi: 10.1371/journal.pone.0018228
15. Bar-David S, Saltz, D, Dayan T, Shkedy Y (2008) Using spatially expanding populations as a tool for evaluating landscape planning: the reintroduced Persian fallow deer as a case study. J Nat Conserv 16:164-174. doi: 10.1016/j.jnc.2008.09.004

16. Baskent, EZ, Celik DA (2013) Forecasting forest development through modeling based on the legacy of forest structure over the past 43 years. Forest Syst 22:232-240. doi: 10.5424/fs/2013222-03516
17. Bedia J, Herrera S, Camia A, Moreno JM, Gutiérrez J.M (2014) Forest fire danger projections in the Mediterranean using ENSEMBLES regional climate change scenarios Climatic Change 122:185-199. doi: 10.1007/s10584-013-1005-z
18. Bedia J, Herrera S, Gutiérrez JM, Benali A, Brands S, Mota B, Moreno JM (2015) Global patterns in the sensitivity of burned area to fire-weather: Implications for climate change. Agr Forest Meteorolog 214: 369-379.doi: 10.1016/j.agrformet.2015.09.002
19. Bellot, J, Bonet, A, Sanchez, J.R, Chirino, E, 2001. Likely effects of land use changes on the runoff and aquifer recharge in a semiarid landscape using a hydrological model. Landscape Urban Plan 55:41-53. doi: 10.1016/S0169-2046(01)00118-9
20. Benito B, Lorite J, Peñas J (2011) Simulating potential effects of climatic warming on altitudinal patterns of key species in Mediterranean-alpine ecosystems. Climatic Change 108:471-483. doi: 0.1007/s10584-010-0015-3
21. Benito-Garzón M, Ruiz-Benito P, Zavala MA (2013) Interspecific differences in tree growth and mortality responses to environmental drivers determine potential species distributional limits in Iberian forests. Global Ecol Biogeogr 22:1141-115. doi: 10.1111/geb.12075
22. Benito-Garzón M, Sánchez de Dios R, Sainz Ollero H (2008) Effects of climate change on the distribution of Iberian tree species. Appl Veg Sci 11:169-178. doi: 10.3170/2008-7-18348
23. Benito-Garzón M, Sánchez de Dios R, Sainz Ollero H (2008) The evolution of the *Pinus sylvestris* L. area in the Iberian Peninsula from the last glacial maximum to 2100 under climate change. The Holocene 18 :705-714. doi: 10.1177/0959683608091781
24. Bertrand R, Perez V, Gégout JC (2012) Disregarding the edaphic dimension in species distribution models leads to the omission of crucial spatial information under climate change: the case of *Quercus pubescens* in France. Global Change Biol 18:2648-2660. doi: 10.1111/j.1365-2486.2012.02679.x
25. Bottalico, F, Pesola, L, Vizzarri, M, Antonello, L, Barbati, A, Chirici, G, Corona, P, Cullotta S, Garfì V, Giannico V, Lafortezza R, Lombardi F, Marchetti M, Nocentini S, Riccioli F, Travaglini D, Sallustio L (2016) Modeling the influence of alternative forest management scenarios on wood production and carbon storage: A case study in the Mediterranean region. Environ Res 144:72-87. doi: 10.1016/j.envres.2015.10.025
26. Bouyer O, Serengil Y (2016) Carbon stored in harvested wood products in Turkey and projections for 2020. Journal of the Faculty of Forestry Istanbul University| İstanbul Üniversitesi Orman Fakültesi Dergisi 66:295-302. doi: 10.17099/jffiu.48603
27. Bravo F, Bravo-Oviedo A, Diaz-Balteiro L (2008) Carbon sequestration in Spanish Mediterranean forests under two management alternatives: a modeling approach. Eur J For Res 127:225-234. doi: 10.1007/s10342-007-0198-y
28. Bravo-Oviedo, A, Gallardo-Andres, C, del Río, M, Montero, G (2010) Regional changes of *Pinus pinaster* site index in Spain using a climate-based dominant height model. Can J Forest Res 40:2036-2048. doi: 10.1139/X10-143
29. Brotons L, Aquilué N, De Cáceres M, Fortin MJ, Fall A (2013) How fire history, fire suppression practices and climate change affect wildfire regimes in Mediterranean landscapes. PLOS one 8: p.e62392. doi: 10.1371/journal.pone.0062392
30. Cáceres M, Brotons L, Aquilué N, Fortin MJ (2013) The combined effects of land-use legacies and novel fire regimes on bird distributions in the Mediterranean. J Biogeogr 40:1535-1547. doi: 10.1111/jbi.12111
31. Calleja JA, Benito Garzón M, Sáinz Ollero H (2009) A Quaternary perspective on the conservation prospects of the Tertiary relict tree *Prunus lusitanica* L. J Biogeogr 36:487-498.doi: 10.1111/j.1365-2699.2008.01976.x
32. Carvalho A, Flannigan MD, Logan KA, Gowman LM, Miranda AI, Borrego C (2010) The impact of spatial resolution on area burned and fire occurrence projections in

Portugal under climate change. Climatic Change 98:177-197. doi: 0.1007/s10584-009-9667-2
33. Carvalho A, Monteiro A, Flannigan M, Solman S, Miranda AI, Borrego C (2011) Forest fires in a changing climate and their impacts on air quality. Atmos Environ 45: 5545-5553. doi: 10.1016/j.atmosenv.2011.05.010
34. Carvalho AC, Carvalho A, Martins H, Marques C, Rocha A, Borrego C, Viegas DX, Miranda A.I (2011) Fire weather risk assessment under climate change using a dynamical downscaling approach. Environ Modell Softw, 26:1123-1133. doi: 10.1016/j.envsoft.2011.03.012
35. Cheddadi R, Fady B, François L, Hajar L, Suc JP, Huang K, Demarteau M, Vendramin GG, Ortu E (2009) Putative glacial refugia of Cedrus atlantica deduced from Quaternary pollen records and modern genetic diversity. J Biogeogr 36:1361-1371. doi: 10.1111/j.1365-2699.2008.02063.x
36. Cheddadi R, Guiot J, Jolly D (2001) The Mediterranean vegetation: what if the atmospheric CO2 increased? Landscape Ecol 16: 667-675. doi: 10.1023/A:1013149831734
37. Chiesi M, Moriondo M, Maselli F, Gardin L, Fibbi L, Bindi M, Running SW (2010) Simulation of Mediterranean forest carbon pools under expected environmental scenarios. Can J Forest Res 40:850-860. doi: 10.1139/X10-037
38. Chiti T, Certini G, Perugini L, Mastrolonardo G, Papale D, Valentini R (2011) Soil carbon dynamics in a Mediterranean forest during the Kyoto Protocol commitment periods. Reg Environ Change 11:371-376. doi: 10.1007/s10113-010-0141-5
39. Chiti T, Papale D, Smith P, Dalmonech D, Matteucci G, Yeluripati J, Rodeghiero M, Valentini R (2010) Predicting changes in soil organic carbon in mediterranean and alpine forests during the Kyoto Protocol commitment periods using the CENTURY model. Soil Use Manage 26:475-484. doi: 10.1111/j.1475-2743.2010.00300.x
40. Coelho MB, Paulo JA, Palma JHN, Tomé M (2012) Contribution of cork oak plantations installed after 1990 in Portugal to the Kyoto commitments and to the landowners economy. Forest Policy Econ 17 :59-68. doi: 10.1016/j.forpol.2011.10.005
41. Condés S, García-Robredo F (2012) An empirical mixed model to quantify climate influence on the growth of *Pinus halepensis* Mill. stands in South-Eastern Spain. Forest Ecol Manag, 284 :59-68. doi: 10.1016/j.foreco.2012.07.030.
42. D'Andrea M, Fiorucci P, Holmes TP (2010) A stochastic Forest Fire Model for future land cover scenarios assessment. Nat Hazard Eearth Sys, 10: 2161-2167. doi: 10.5194/nhess-10-2161-2010
43. Davi, H, Dufrêne, E, Francois, C, Le Maire, G, Loustau, D, Bosc, A, Rambal, S, Granier, A, Moors, E (2006) Sensitivity of water and carbon fluxes to climate changes from 1960 to 2100 in European forest ecosystems. Agr Forest Meteorol 141 :35-56. doi: 10.1016/j.agrformet.2006.09.003
44. De Marco A (2009) Assessment of present and future risk to Italian forests and human health: modelling and mapping. Environ Pollut 157:1407-1412. doi: 10.1016/j.envpol.2008.09.047
45. Del Rio S, Penas A, Perez-Romero R (2005) Potential areas of deciduous forests in Spain (Castile and Leon) according to future climate change. Plant Biosyst 139: 222-233. doi: 10.1127/0340-269X/2006/0036-0045
46. de-Miguel S, Bonet JA, Pukkala T, de Aragón JM (2014) Impact of forest management intensity on landscape-level mushroom productivity: a regional model-based scenario analysis. Forest Ecol Manag, 330 :218-227. doi: 10.1016/j.foreco.2014.07.014
47. Desprez-Loustau ML, Robin C, Reynaud G, Déqué M, Badeau V, Piou D, Husson C, Marçais B (2007) Simulating the effects of a climate-change scenario on the geographical range and activity of forest-pathogenic fungi. Can J Plant Pathol 29:101-120. doi: 10.1080/07060660709507447
48. Di Febbraro M, Roscioni F, Frate L, Carranza ML, De Lisio L, De Rosa D, Marchetti M, Loy,A (2015) Long-term effects of traditional and conservation-oriented forest

management on the distribution of vertebrates in Mediterranean forests: a hierarchical hybrid modelling approach. Divers Distr 21:1141-1154. doi: 10.1111/ddi.12362
49. Di Traglia, M, Attorre, F, Francesconi, F, Valenti, R, Vitale, M (2011) Is cellular automata algorithm able to predict the future dynamical shifts of tree species in Italy under climate change scenarios? A methodological approach. Ecol Model 222:925-934. doi: 10.1016/j.ecolmodel.2010.12.009
50. Ding H, Chiabai A, Silvestri S, Nunes P.A (2016) Valuing climate change impacts on European forest ecosystems. Ecosyst Serv18:141-153. doi: 10.1016/j.ecoser.2016.02.039
51. Donmez C, Berberoglu S, Curran PJ (2011) Modelling the current and future spatial distribution of NPP in a Mediterranean watershed. Int J Appl Eeearth Obs 13 :336-345. doi: 10.1016/j.jag.2010.12.005
52. Dury M, Hambuckers A, Warnant P, Henrot A, Favre E, Ouberdous M, François, L (2011) Responses of European forest ecosystems to 21st century climate: assessing changes in interannual variability and fire intensity. iForest 4: 82-89. doi: 10.3832/ifor0572-004
53. Eker M (2014) Trends in Woody Biomass Utilization in Turkish Forestry. Croat J For Eng 35:255-270.
54. Esteve-Selma MA, Martínez-Fernández J, Hernández I, Montávez JP, Lopez JJ, Calvo JF, Robledano F (2010) Effects of climatic change on the distribution and conservation of Mediterranean forests: the case of *Tetraclinis articulata* in the Iberian Peninsula. Biodivers Conserv 19:3809-3825. doi: 10.1007/s10531-010-9928-4
55. Fabre B, Piou D, Desprez-Loustau ML, Marcais B (2011) Can the emergence of pine Diplodia shoot blight in France be explained by changes in pathogen pressure linked to climate change?. Global Change Biol 17: 3218-3227.doi: 10.1111/j.1365-2486.2011.02428.x
56. Fernández-de-Uña L, Cañellas I, Gea-Izquierdo G (2015) Stand competition determines how different tree species will cope with a warming climate. PloS one 10: p.e0122255. doi: 10.1371/journal.pone.0122255
57. Fonseca TF, Cerveira A, Mota A (2012) An integer programming model for a forest harvest problem in Pinus pinaster stands. For Syst, 21: 272-283. doi: 10.5424/fs/2012212-02879
58. Fotakis D, Sidiropoulos E, Loukas A (2014) Integration of a hydrological model within a geographical information system: application to a forest watershed. Water 6: 500-516. doi: 10.3390/w6030500
59. Francaviglia R, Coleman K, Whitmore AP, Doro L, Urracci G, Rubino M, Ledda L (2012) Changes in soil organic carbon and climate change–Application of the RothC model in agro-silvo-pastoral Mediterranean systems. Agr Syst 112:48-54. doi: 10.1016/j.agsy.2012.07.001
60. Franz KW, Romanowski J, Saavedra D (2011) Effects of prospective landscape changes on species viability in Segre River valley, NE Spain. Landscape Urban Plan 100: 242-250. doi: 10.1016/j.landurbplan.2010.12.011
61. Fyllas NM, Phillips OL, Kunin WE, Matsinos YG, Troumbis AI (2007) Development and parameterization of a general forest gap dynamics simulator for the North-eastern Mediterranean Basin (GREek FOrest Species). Ecol Model 204: 439-456. doi: 10.1016/j.ecolmodel.2007.02.006
62. Fyllas NM, Politi PI, Galanidis A, Dimitrakopoulos PG, Arianoutsou M (2010) Simulating regeneration and vegetation dynamics in Mediterranean coniferous forests. Ecol Model 221: 1494-1504. doi: 10.1016/j.ecolmodel.2010.03.003
63. Fyllas NM, Troumbis AY (2009) Simulating vegetation shifts in north-eastern Mediterranean mountain forests under climatic change scenarios. Global Ecol Biogeogr, 18: 64-77. doi: 10.1111/j.1466-8238.2008.00419.x
64. Gallardo M, Gómez I, Vilar L, Martínez-Vega J, Martín MP (2016) Impacts of future land use/land cover on wildfire occurrence in the Madrid region (Spain). Reg Environ Change 16:1047-1061. doi: 10.1007/s10113-015-0819-9

65. García-López JM, Allué C (2010) Effects of climate change on the distribution of Pinus sylvestris L. stands in Spain. A phytoclimatic approach to defining management alternatives. For Syst 19:329-339. doi: 10.5424/fs/2010193-8694
66. García-López JM, Allué C (2011) Modelling phytoclimatic versatility as a large scale indicator of adaptive capacity to climate change in forest ecosystems. Ecol Model 222: 1436-1447. doi: 10.1016/j.ecolmodel.2011.02.001
67. García-Valdés R, Svenning JC, Zavala MA, Purves DW, Araújo MB (2015) Evaluating the combined effects of climate and land-use change on tree species distributions. J Appl Ecol 52: 902-912. doi: 10.1111/1365-2664.12453
68. García-Valdés R, Zavala MA, Araujo MB, Purves DW (2013) Chasing a moving target: Projecting climate change-induced shifts in non-equilibrial tree species distributions. J Ecol 101: 441-453. doi: 10.1111/1365-2745.12049
69. Gaucherel C, Griffon S, Misson L, Houet T (2010) Combining process-based models for future biomass assessment at landscape scale. Land Ecol 25: 201-215. doi: 10.1007/s10980-009-9400-6
70. Gaucherel C, Guiot J, Misson L (2008) Changes of the potential distribution area of French Mediterranean forests under global warming. Biogeosciences 5:1493-1504. doi: 10.5194/bg-5-1493-2008
71. Gibbons P, Lindenmayer DB, Fischer J, Manning AD, Weinberg A, Seddon J, Ryan P, Barrett G (2008) The future of scattered trees in agricultural landscapes. Conserv Biol 22:1309-1319. doi: 10.1111/j.1523-1739.2008.00997.x
72. Gil-Tena A, Aquilué N, Duane A, De Cáceres M, Brotons L (2016) Mediterranean fire regime effects on pine-oak forest landscape mosaics under global change in NE Spain. Eur J For Res 135:403-416. doi: 10.1007/s10342-016-0943-1
73. Górriz-Mifsud E, Varela E, Piqué M, Prokofieva I (2016) Demand and supply of ecosystem services in a Mediterranean forest: computing payment boundaries. Ecosyst Serv 17:53-63. doi: 10.1016/j.ecoser.2015.11.006
74. Hajar L, François L, Khater C, Jomaa I, Déqué M, Cheddadi R (2010) *Cedrus libani* (A. Rich) distribution in Lebanon: Past, present and future. C R Biol 333: 622-630. doi: 10.1016/j.crvi.2010.05.003
75. Hanewinkel M, Cullmann DA, Schelhaas MJ, Nabuurs GJ, Zimmermann NE (2013) Climate change may cause severe loss in the economic value of European forest land. Nat Clim Change 3: 203-207. doi: 10.1038/nclimate1687
76. Haran J, Roques A, Bernard A, Robinet C, Roux G (2015) Altitudinal barrier to the spread of an invasive species: could the Pyrenean chain slow the natural spread of the pinewood nematode?. PloS one 10: e0134126. doi: 10.1371/journal.pone.0134126
77. Henne PD, Elkin C, Franke J, Colombaroli D, Calò C, La Mantia T, Pasta S, Conedera M, Dermody O, Tinner W (2015) Reviving extinct Mediterranean forest communities may improve ecosystem potential in a warmer future. Front Ecol Environ 13:356-362. doi: 10.1890/150027
78. İpekdal K, Beton D (2014) Model Predicts a Future Pine Processionary Moth Risk in Artvin and Adjacent Regions. Artvin Çoruh Üniversitesi Orman Fakültesi Dergisi 15: 85-95. doi: 10.17474/acuofd.62914
79. Kadioğullari AI, Keleş S, Başkent EZ, Bingöl Ö (2015) Controlling spatial forest structure with spatial simulation in forest management planning: a case study from turkey. Sains Malays 44: 325-33.
80. Kalabokidis K, Palaiologou P, Gerasopoulos E, Giannakopoulos C, Kostopoulou E, Zerefos C (2015) Effect of climate change projections on forest fire behavior and values-at-risk in Southwestern Greece. Forests 6: 2214-2240. doi: 10.3390/f6062214
81. Kaligarič M, Ivajnšič D (2014) Vanishing landscape of the "classic" Karst: changed landscape identity and projections for the future. Land Urban Plan 132: 148-158. doi: 10.1016/j.landurbplan.2014.09.004
82. Karali A, Hatzaki M, Giannakopoulos C, Roussos A, Xanthopoulos G, Tenentes V (2014) Sensitivity and evaluation of current fire risk and future projections due to climate

change: the case study of Greece. Nat Hazard Eearth Sys 14:143-153.doi: 10.5194/nhess-14-143-2014
83. Katunar L, Kobler A (2011) Prediction of forest vegetation shift due to different climate-change scenarios in Slovenia. Sumar List 135: 113-125.
84. Keenan T, González RG, Jorba SS, Alonso CG (2007) Process based forest modelling: a thorough validation and future prospects for mediterranean forests in a changing world. Cuadernos de la Sociedad Espanola de Ciencias Forestales 23: 81-92.
85. Keenan T, Maria Serra J, Lloret F, Ninyerola M, Sabate S (2011) Predicting the future of forests in the Mediterranean under climate change, with niche- and process-based models: CO2 matters!. Global Change Biol 17: 565-579. doi: 10.1111/j.1365-2486.2010.02254.x
86. Koniak G, Noy-Meir I (2009) A hierarchical, multi-scale, management-responsive model of Mediterranean vegetation dynamics. Ecol Model, 220:1148-1158. doi: 10.1016/j.ecolmodel.2009.01.036
87. Koniak G, Noy-Meir I, Perevolotsky A (2011) Modelling dynamics of ecosystem services basket in Mediterranean landscapes: a tool for rational management. Land Ecol 26:109-124. doi: 10.1007/s10980-010-9540-8
88. Lasserre B, Chirici G, Chiavetta U, Garfì V, Tognetti R, Drigo R, DiMartino P, Marchetti M (2011) Assessment of potential bioenergy from coppice forests trough the integration of remote sensing and field surveys. Biomass Bioenerg 35: 716-724. doi: 10.1016/j.biombioe.2010.10.013
89. Leal AI, Rainho A, Martins RC, Granadeiro JP, Palmeirim JM (2016) Modelling future scenarios to improve woodland landscapes for birds in the Mediterranean. J Nat Conserv 30:103-112. doi: 10.1016/j.jnc.2016.02.001
90. Lehsten V, Sykes MT, Scott AV, Tzanopoulos J, Kallimanis A, Mazaris A, Verburg PH, Schulp CJ, Potts SG, Vogiatzakis I (2015) Disentangling the effects of land-use change, climate and CO2 on projected future European habitat types. Global Ecol Biogeogr 24: 653-663. doi: 10.1111/geb.12291
91. Lesschen JP, Schoorl JM, Cammeraat LH (2009) Modelling runoff and erosion for a semi-arid catchment using a multi-scale approach based on hydrological connectivity. Geomorphology 109: 174-183. doi: 10.1016/j.geomorph.2009.02.030
92. Lloret F, Martinez-Vilalta J, Serra-Diaz JM, Ninyerola M (2013) Relationship between projected changes in future climatic suitability and demographic and functional traits of forest tree species in Spain. Climatic Change 120: 449-462. doi: 10.1007/s10584-013-0820-6
93. Lloret F, Pausas JG, Vilà M (2003) Responses of Mediterranean Plant Species to different fire frequencies in Garraf Natural Park (Catalonia, Spain): field observations and modelling predictions. Plant Ecol 167: 223-235. doi: 10.1023/A:1023911031155
94. Lobianco A, Delacote P, Caurla S, Barkaoui A (2016) Accounting for active management and risk attitude in forest sector models. Environ Model Assess 21: 391-405. doi: 10.1007/s10666-015-9483-1
95. Loepfe L, Martinez-Vilalta J, Piñol J (2012) Management alternatives to offset climate change effects on Mediterranean fire regimes in NE Spain. Climatic Change, 115: 693-707. doi: 10.1007/s10584-012-0488-3
96. López-Tirado J, Hidalgo PJ (2016) Predictive modelling of climax oak trees in southern Spain: insights in a scenario of global change. Plant Ecol 217: 451-463. doi: 10.1007/s11258-016-0589-6
97. López-Tirado, J, Hidalgo, P.J (2016) Ecological niche modelling of three Mediterranean pine species in the south of Spain: a tool for afforestation/reforestation programs in the twenty-first century. New Forests 47:411-429. doi: 10.1007/s11056-015-9523-3
98. Lopez-Vicente M, Poesen J, Navas A, Gaspar L (2013) Predicting runoff and sediment connectivity and soil erosion by water for different land use scenarios in the Spanish Pre-Pyrenees. Catena 102: 62-73. doi: 10.1016/j.catena.2011.01.001
99. Loustau D, Bosc A, Colin A, Ogée J, Davi,H, François C, Dufrêne E, Déqué M, Cloppet E, Arrouays D, Le Bas C (2005) Modeling climate change effects on the potential

production of French plains forests at the sub-regional level. Tree Physiol 25: 813-823. doi: 10.1093/treephys/25.7.813
100. Lupon A, Gerber S, Sabater F, Bernal S (2015) Climate response of the soil nitrogen cycle in three forest types of a headwater Mediterranean catchment. Biogeosciences 120: 859-875. doi: 10.1002/2014JG002791
101. Lurz PWW, Rushton SP, Wauters LA, Bertolino S, Currado I, Mazzoglio P, Shirley MDF(2001) Predicting grey squirrel expansion in North Italy: a spatially explicit modelling approach. Land Ecol 16: 407-420. doi: 10.1023/A:1017508711713
102. Manso R, Pukkala T, Pardos M, Miina J, Calama R (2013) Modelling *Pinus pinea* forest management to attain natural regeneration under present and future climatic scenarios. Can J Forest Res 44: 250-262. doi: 10.1139/cjfr-2013-0179
103. Marchi M, Jørgensen SE, Pulselli FM, Marchettini N, Bastianoni S (2012) Modelling the carbon cycle of Siena Province (Tuscany, central Italy). Ecolo Model 225: 40-60. doi: 10.1016/j.ecolmodel.2011.11.007
104. Márquez AL, Real R, Olivero J, Estrada A (2011) Combining climate with other influential factors for modelling the impact of climate change on species distribution. Climatic Change 108:135-157. doi: 10.1007/s10584-010-0010-8
105. Martin-Benito D, Kint V, Del Rio M, Muys B, Cañellas I (2011) Growth responses of West-Mediterranean Pinus nigra to climate change are modulated by competition and productivity: past trends and future perspectives. Forest Ecol Manag 262: 1030-1040. doi: 10.1016/j.foreco.2011.05.038
106. Maselli, F, Moriondo, M, Chiesi, M, Chirici, G, Puletti, N, Barbati, A, Corona, P (2009) Evaluating the effects of environmental changes on the gross primary production of Italian forests. Remote Sens 1:1108-1124. doi: 10.3390/rs1041108
107. Migliavacca M, Dosio A, Camia A, Hobourg R, Houston-Durrant T, Kaiser JW, Khabarov N, Krasovskii AA, Marcolla B, Miguel-Ayanz S, Ward DS, Cescatti A (2013) Modeling biomass burning and related carbon emissions during the 21st century in Europe. Biogeosciences 118: 1732-1747. doi: 10.1002/2013JG002444
108. Milne R, Van Oijen M (2005) A comparison of two modelling studies of environmental effects on forest carbon stocks across Europe. Ann For Sci 62: 911-923. doi: 10.1051/forest:2005082
109. Moriondo M, Good P, Durao R, Bindi M, Giannakopoulos C, Corte-Real J (2006) Potential impact of climate change on fire risk in the Mediterranean area. Climate Res 31: 85-95. doi: 10.3354/cr031085
110. Mouillot F, Rambal S, Joffre R (2002) Simulating climate change impacts on fire frequency and vegetation dynamics in a Mediterranean-type ecosystem. Global Change Biol 8: 423-437. doi: 10.1046/j.1365-2486.2002.00494.x
111. Mueller EN, Francke T, Batalla RJ, Bronstert A (2009) Modelling the effects of land-use change on runoff and sediment yield for a meso-scale catchment in the Southern Pyrenees. Catena 79: 288-296. doi: 10.1016/j.catena.2009.06.007
112. Muñoz-Rojas M, Doro L, Ledda L, Francaviglia R (2015) Application of CarboSOIL model to predict the effects of climate change on soil organic carbon stocks in agro-silvo-pastoral Mediterranean management systems. Agr Ecosyst Environ 202:8-16. doi: 10.1016/j.agee.2014.12.014
113. Muñoz-Rojas M, Jordán A, Zavala LM, González-Peñaloza FA, De la Rosa D, Pino-Mejias R, Anaya-Romero M (2013) Modelling soil organic carbon stocks in global change scenarios: a CarboSOIL application. Biogeosciences 10: 8253-8268. doi: 10.5194/bg-10-8253-2013
114. Mur RJ, Goetz RU, Xabadia A, Córdoba F, Gracia C (2014) Adapting the optimal selective-logging of Scots pine (*Pinus sylvestris* L.) stands in NE Spain to increasing CO 2 concentrations. J Forest Econ 20: 286-304. doi: 10.1016/j.jfe.2014.09.001
115. Nunes L, Gower ST, Peckham SD, Magalhães M, Lopes D, Rego FC (2014) Estimation of productivity in pine and oak forests in northern Portugal using Biome-BGC. Forestry 88: 200-212. doi: 10.1093/forestry/cpu044

116. Ohlemüller R, Gritti ES, Sykes MT, Thomas CD (2006) Quantifying components of risk for European woody species under climate change. Global Change Biol 12:1788-1799. doi: 10.1111/j.1365-2486.2006.01231.x
117. Önder, D, Aydin, M, berberoğlu, s, Önder, S, Yano, T (2009) The use of aridity index to assess implications of climatic change for land cover in Turkey. Turk J Agric For 33: 305-314. doi: 10.3906/tar-0810-21
118. Öztürk M, Copty NK, Saysel AK (2013) Modeling the impact of land use change on the hydrology of a rural watershed. J Hydrol 497: 97-109. doi: 0.1016/j.jhydrol.2013.05.022
119. Pacheco FAL, Santos, RMB, Fernandes LS, Pereira MG, Cortes RMV (2015) Controls and forecasts of nitrate yields in forested watersheds: A view over mainland Portugal. Sci Total Environ 537: 421-440. doi: 10.1016/j.scitotenv.2015.07.127
120. Palma JH, Paulo JA, Faias SP, Garcia-Gonzalo J, Borges JG, Tomé M (2015) Adaptive management and debarking schedule optimization of *Quercus suber* L. stands under climate change: case study in Chamusca, Portugal. Reg Environ Change 15:1569-1580. doi: 10.1007/s10113-015-0818-x
121. Palma, J.H.N, Paulo, J.A, Tomé, M, 2014. Carbon sequestration of modern *Quercus suber* L. silvoarable agroforestry systems in Portugal: a YieldSAFE-based estimation. Agroforest Syst 88: 791-801. doi: 0.1007/s10457-014-9725-2
122. Pardos M, Calama R, Maroschek M, Rammer W, Lexer MJ (2015) A model-based analysis of climate change vulnerability of Pinus pinea stands under multiobjective management in the Northern Plateau of Spain. Ann Forest Sci 72: 1009-1021. doi: 10.1007/s13595-015-0520-7
123. Pausas JG (1999) Response of plant functional types to changes in the fire regime in Mediterranean ecosystems: a simulation approach. J Veg Sci 10: 717-722. doi: 10.2307/3237086
124. Pausas JG (2006) Simulating Mediterranean landscape pattern and vegetation dynamics under different fire regimes. Plant Ecol 187: 249-259. doi: 10.1007/s11258-006-9138-z
125. Pausas JG, Lloret F (2007) Spatial and temporal patterns of plant functional types under simulated fire regimes. Int J Wildland Fire 16: 484-492. doi: 10.1071/WF06109
126. Pereira MG, Calado TJ, DaCamara CC, Calheiros T (2013) Effects of regional climate change on rural fires in Portugal. Climate Research 57:187-200. doi: 10.3354/cr01176
127. Pereira S, Prieto A, Calama R, Diaz-Balteiro L (2015) Optimal management in *Pinus pinea* L. stands combining silvicultural schedules for timber and cone production. Silva Fenn 49: 1226. doi: 10.14214/sf.1226
128. Pilli R, Grassi G, Kurz WA, Smyth CE, Blujdea V (2013) Application of the CBM-CFS3 model to estimate Italy's forest carbon budget, 1995–2020. Ecol Model 266: 144-171. doi: 10.1016/j.ecolmodel.2013.07.007
129. Pilli R, Grassi G, Moris JV, Kurz WA (2014) Assessing the carbon sink of afforestation with the Carbon Budget Model at the country level: an example for Italy. iForest 8: 410-421. doi: 10.3832/ifor1257-007
130. Pique-Nicolau M, del-Rio M, Calama R, Montero G (2011) Modelling silviculture alternatives for managing *Pinus pinea* L. forest in North-East Spain. Forest Syst 20: 3-20
131. Piquer-Rodríguez M, Kuemmerle T, Alcaraz-Segura D, Zurita-Milla R, Cabello J (2012) Future land use effects on the connectivity of protected area networks in southeastern Spain. J Nat Conserv 20: 326-336. doi: 10.1016/j.jnc.2012.07.001
132. Ragaglini, G, Villani, R, Guidi, W, Bonari, E (2008) Bioenergy production assessment at regional level under different scenarios of resources exploitation. Aspects of Applied Biology, 90:109-118.
133. Regos A, D'Amen M, Herrando S, Guisan A, Brotons L (2015) Fire management, climate change and their interacting effects on birds in complex Mediterranean landscapes: dynamic distribution modelling of an early-successional species—the near-threatened Dartford Warbler (*Sylvia undata*). J Ornithol 156:275-286. doi: 10.1007/s10336-015-1174-9
134. Regos A, D'Amen M, Titeux N, Herrando S, Guisan A, Brotons L (2016) Predicting the future effectiveness of protected areas for bird conservation in Mediterranean ecosystems

under climate change and novel fire regime scenarios. Divers Distrib 22: 83-96. doi: 10.1111/ddi.12375
135. Retana J, Maria Espelta J, Habrouk A, Luis Ordoñez J, de Solà-Morales F (2002) Regeneration patterns of three Mediterranean pines and forest changes after a large wildfire in northeastern Spain. Ecoscience 9:89-97. doi: 10.1080/11956860.2002.11682694
136. Río SD, Penas A (2006) Potential areas of evergreen forests in Castile and Leon (Spain) according to future climate change. Phytocoenologia 36:45-66. doi: 10.1127/0340-269X/2006/0036-0045
137. Rivaes R, Rodríguez-González PM, Albuquerque A, Pinheiro AN, Egger G, Ferreira MT (2013) Riparian vegetation responses to altered flow regimes driven by climate change in Mediterranean rivers. Ecohydrology 6:413-424. doi: 10.1002/eco.1287
138. Robinet C, Rousselet J, Roques A (2014) Potential spread of the pine processionary moth in France: preliminary results from a simulation model and future challenges. Ann Forest Sci 71: 149-160. doi: 10.1007/s13595-013-0287-7
139. Robinet C, Van Opstal N, Baker R, Roques A (2011) Applying a spread model to identify the entry points from which the pine wood nematode, the vector of pine wilt disease, would spread most rapidly across Europe. Biol Invasions 13: 2981-2995. doi: 10.1007/s10530-011-9983-0
140. Rochdane S, Bounoua L, Zhang P, Imhoff ML, Messouli M, Yacoubi-Khebiza M (2014) Combining satellite data and models to assess vulnerability to climate change and its impact on food security in Morocco. Sustainability 6: 1729-1746. doi: 10.3390/su6041729
141. Ruiz-Labourdette D, Nogués-Bravo D, Ollero HS, Schmitz MF, Pineda FD (2012) Forest composition in Mediterranean mountains is projected to shift along the entire elevational gradient under climate change. J Biogeogr 39:162-176. doi: 10.1111/j.1365-2699.2011.02592.x
142. Ruiz-Labourdette D, Schmitz MF, Pineda FD (2013) Changes in tree species composition in Mediterranean mountains under climate change: indicators for conservation planning. Ecol Indic 24:310-323. doi: 10.1016/j.ecolind.2012.06.021
143. Rulli, M.C, Offeddu, L, Santini, M (2013) Modeling post-fire water erosion mitigation strategies. Hydrol Earth Syst Sc 17: 2323-2337. doi: :10.5194/hess-17-2323-2013
144. Sabaté S, Gracia CA, Sánchez A (2002) Likely effects of climate change on growth of *Quercus ilex*, *Pinus halepensis*, *Pinus pinaster*, *Pinus sylvestris* and *Fagus sylvatica* forests in the Mediterranean region. Forest Ecol Manag 162:23-37. doi: 10.1016/S0378-1127(02)00048-8
145. Sánchez De Dios R, Benito-Garzón M, Sainz-Ollero H (2009) Present and future extension of the Iberian submediterranean territories as determined from the distribution of marcescent oaks. Plant Ecol 204:189-205. doi: 10.1007/s11258-009-9584-5
146. Santini M, Collalti A, Valentini R (2014) Climate change impacts on vegetation and water cycle in the Euro-Mediterranean region, studied by a likelihood approach. Reg Environ Change 14:1405-1418. doi: 10.1007/s10113-013-0582-8
147. Schelhaas MJ, Nabuurs GJ, Hengeveld G, Reyer C, Hanewinkel M, Zimmermann NE, Cullmann D (2015) Alternative forest management strategies to account for climate change-induced productivity and species suitability changes in Europe. Reg Environ Change 15: 1581-1594. doi: 10.1007/s10113-015-0788-z
148. Schröter D, Cramer W, Leemans R, Prentice I.C, Araújo MB, Arnell NW, Bondeau A, Bugmann H, Carter TR, Gracia CA, de la Vega-Leinert AC, Erhard M, Ewert E, Glendining M, House JI, Kankaanpää S. Klein RJT, Lavorel S, Lindner M, Metzger MJ, Meyer J, Mitchell TD, Reginster I, Rounsevell M, Sabaté

S, Sitch S, Smith B, Smith J, Smith P, Sykes MT, Thonicke K, Thuiller W, Tuck G, Zaehle S, Zierl B (2005) Ecosystem service supply and vulnerability to global change in Europe. Science 310: 1333-1337. doi: 10.1126/science.1115233
149. Serpa D, Nunes JP, Santos J, Sampaio E, Jacinto R, Veiga S, Lima JC, Moreira M, Corte-Real J, Keizer JJ, Abrantes N (2015) Impacts of climate and land use changes on the hydrological and erosion processes of two contrasting Mediterranean catchments. Sci Total Environ 538: 64-77. doi: 10.1016/j.scitotenv.2015.08.033
150. Silva JS, Vaz P, Moreira F, Catry F, Rego FC (2011) Wildfires as a major driver of landscape dynamics in three fire-prone areas of Portugal. Land Urban Plan 101: 349-358. doi: 10.1016/j.landurbplan.2011.03.001
151. Simonson W, Ruiz-Benito P, Valladares F, Coomes DA (2016) Modelling above-ground carbon dynamics using multi-temporal airborne lidar: insights from a Mediterranean woodland. Biogeosciences, 13: 961-973. doi: 10.5194/bgd-12-14739-2015
152. Sousa P., Trigo RM, Pereira MG, Bedia J, Gutiérrez JM (2015) Different approaches to model future burnt area in the Iberian Peninsula. Agr Forest Meteorol 202: 11-25. doi: 10.1016/j.agrformet.2014.11.018
153. Temunović M, Frascaria-Lacoste N, Franjić J, Satovic Z, Fernández-Manjarrés JF (2013) Identifying refugia from climate change using coupled ecological and genetic data in a transitional Mediterranean-temperate tree species. Mol Ecol 22: 2128-2142. doi: https://doi.org/10.1111/mec.12252
154. Terranova O, Antronico L, Coscarelli R, Iaquinta P (2009) Soil erosion risk scenarios in the Mediterranean environment using RUSLE and GIS: an application model for Calabria (southern Italy). Geomorphology 112: 228-245. doi: 10.1016/j.geomorph.2009.06.009
155. Turco M, Llasat MC, von Hardenberg J, Provenzale A (2014) Climate change impacts on wildfires in a Mediterranean environment. Climatic Change 125: 369-380. doi: 10.1007/s10584-014-1183-3
156. Vacquie LA, Houet T, Sohl TL, Reker R, Sayler KL (2015) Modelling regional land change scenarios to assess land abandonment and reforestation dynamics in the Pyrenees (France). J Mt Sci12: 905-920. doi: 10.1007/s11629-014-3405-6
157. Vázquez A, Climent JM, Casais L, Quintana JR (2015) Current and future estimates for the fire frequency and the fire rotation period in the main woodland types of peninsular Spain: a case-study approach. Forest Syst 24: 31-43. doi: 10.5424/fs/2015242-06454.
158. Vázquez de la Cueva A, Quintana JR, Cañellas I (2012) Fire activity projections in the SRES A2 and B2 climatic scenarios in peninsular Spain. Int J Wildland Fire 21: 653-665. doi: 10.1071/WF11013.
159. Versini PA, Velasco M, Cabello A, Sempere-Torres D (2013) Hydrological impact of forest fires and climate change in a Mediterranean basin. Nat Hazards 66: 609-628. doi: 10.1007/s11069-012-0503-z
160. Vicente-Serrano SM, Lasanta T, Gracia C (2010) Aridification determines changes in forest growth in *Pinus halepensis* forests under semiarid Mediterranean climate conditions. Agr Forest Meteorol 150:614-628. doi: 10.1016/j.agrformet.2010.02.002
161. Vilà-Cabrera A, Rodrigo A, Martínez-Vilalta J, Retana J (2012) Lack of regeneration and climatic vulnerability to fire of Scots pine may induce vegetation shifts at the southern edge of its distribution. J Biogeogr 39: 488-496. doi: 10.1111/j.1365-2699.2011.02615.x

162. Vilén T, Fernandes PM (2011) Forest fires in Mediterranean countries: CO2 emissions and mitigation possibilities through prescribed burning. Environ Manage 48: 558-567. doi: 10.1007/s00267-011-9681-9
163. Vitale M, Mancini M, Matteucci G, Francesconi F, Valenti R, Attorre F (2012) Model-based assessment of ecological adaptations of three forest tree species growing in Italy and impact on carbon and water balance at national scale under current and future climate scenarios. iForest 5: 235-246. doi: 10.3832/ifor0634-005

Frequency of journals in the selection of 163 papers

Journal name	Number of papers
Ecological Modelling	9
Climatic Change	7
Biogeosciences	6
Forest Systems	6
Global Change Biology	6
Journal of Biogeography	5
Regional Environmental change	5
Annals of Forest Science	4
Forest Ecology and Management	4
iForest-Biogeosciences	4
Landscape and Urban Planning	4
Landscape Ecology	4
Plant Ecology	4
Plos One	4
Agricultural and Forest Meteorology	3
Applied Vegetation Science	3
Can J Forest Res	3
Global Ecol Biogeogr	3
Journal for Nature Conservation	3
Science of the Total Environment	3
Agriculture, Ecosystems & Environment	2
Catena	2
Climate Research	2
Diversity and Distributions	2
Ecosystem Services	2
Environmental Pollution	2
European Journal of Forest Research	2
Geomorphology	2
International Journal of Wildland Fire	2
Natural Hazards and Earth System Sciences	2
Agricultural Systems	1
Agroforestry systems	1
Artvin Çoruh Üniversitesi Orman Fakültesi Dergisi	1
Aspects of Applied Ecology	1
Atmospheric Environment	1
Biodiversity and Conservation	1
Biological Invasions	1
Biomass and Bioenergy	1
Canadian Journal of Plant Pathology	1
Comptes Rendus Biologies	1
Conservation Biology	1
Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering	1

Journal name	Number of papers
Cuadernos de la Sociedad Española de Ciencias Forestales	1
Ecohydrology	1
Ecological Indicators	1
Ecoscience	1
Environmental Modelling & Assessment	1
Environmental Modelling & Software	1
Environmental Reseach	1
Forest Policy and Economics	1
Forestry	1
Forests	1
Frontiers in Ecology and the Environment	1
Hydrology and Earth System Sciences	1
International Journal of Applied Earth Observation and Geoinformation	1
Journal of Applied Ecology	1
Journal of Ecology	1
Journal of Forest Economics	1
Journal of Hydrology	1
Journal of Land Use Science	1
Journal of Mountain Science	1
Journal of Ornithology	1
Journal of the Faculty of Forestry Istanbul University	1
Journal of Vegetation Science	1
Land Degradation & Development	1
Molecular Ecology	1
Nature Climate Change	1
New Forests	1
Phytocoenologia	1
Plant Biosystems	1
Remote Sensing	1
Sains Malaysiana	1
Science	1
Silva Fenn	1
Soil Use and Management	1
Šumarski list	1
Sustainability	1
The Holocene	1
Tree Physiology	1
Turkish Journal of Agriculture and Forestry	1
Water	1
Natural Hazards	1
Environmental Management	1

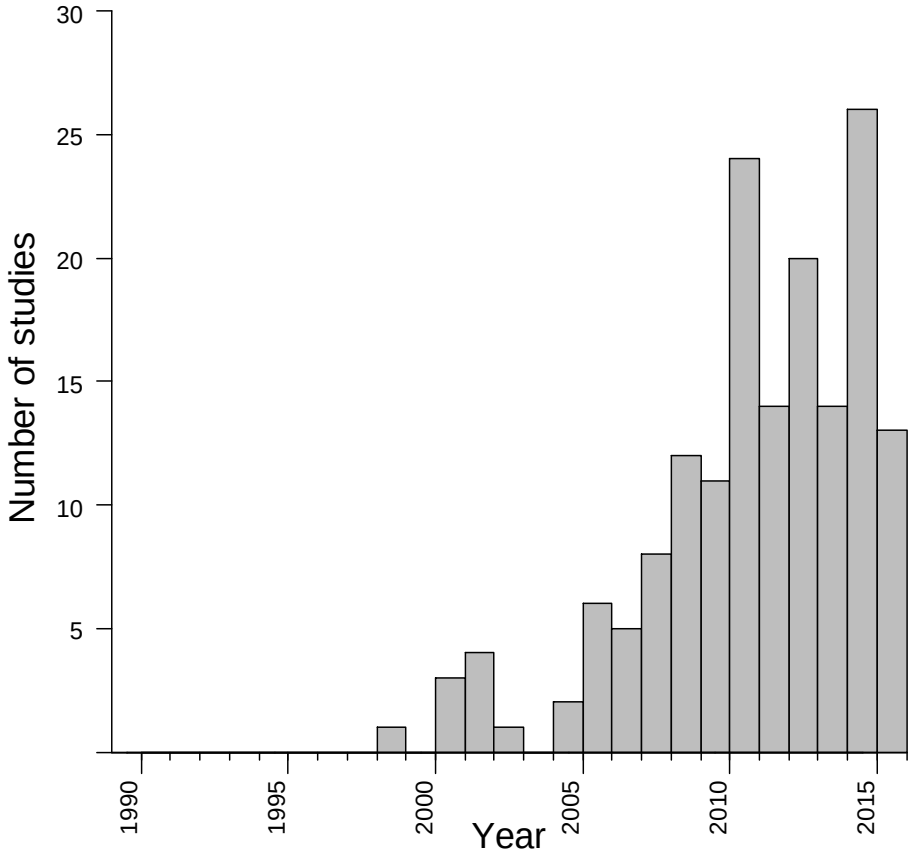
Online resource 3: spatial scales addressed

Number of studies found in the literature review, classified by the original spatial extent/focus of the article and the number of drivers included in the scenarios.

	Number of drivers			
Original extent of the article	**1**	**2**	**3**	**4**
Global	9	3		1
Regional (Pan-Mediterranean)	14			
National	26	10		
SubNational	30	9	1	
Local	37	16	4	
Simulated landscapes (local)	2	1		
Total	163			

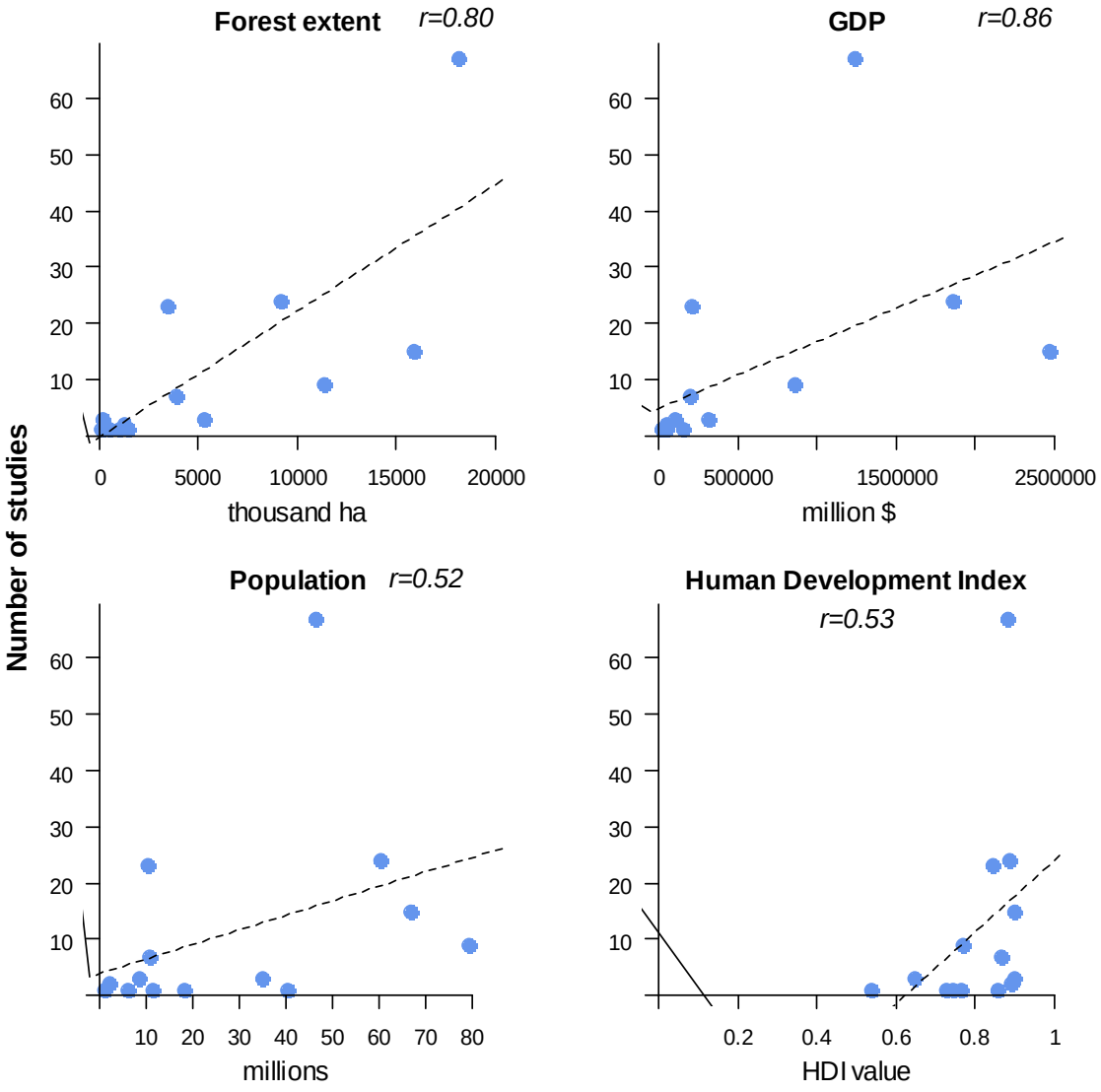
Online resource 4: temporal trend of published literature

Number of published articles that used models and scenarios to forecast nature and/or ecosystem services indicators linked to Mediterranean forests during the period 1990-2016.



Online resource 5: correlations between number of studies and socio-economic indicators.

Number of studies by country in relation to their total forest extent (FAO 2010), Gross Domestic Product (GDP; source: https://data.worldbank.org), population (source: https://data.worldbank.org), and their level of social well-being as measured by the Human Development Index (UNEP 2016). R values indicate Spearman's correlations between each variable and the number of studies by country.



FAO. 2010. Global forest resources assessment 2010. Main report. FAO Forestry Paper No. 163. Rome

UNDP (United Nations Development Programme)–Human Development Report 2016. Human development for Everyone. New York. (also available at http://hdr.undp.org/sites/default/files/2016_human_development_report.pdf)