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A REVIEW ON CLIMATE CHANGE IMPACTS ON FOREST ECOSYSTEM SERVICES IN THE MEDITERRANEAN BASIN

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ABSTRACT

The Mediterranean Basin covers more than 2 million square kilometres and is surrounded by three continents: Africa, Asia and Europe. The Basin that is rich in biodiversity has tilted towards warmer and drier conditions over the last decades. The emerging climatic conditions particularly the increase in the number of climate extremes are bringing new threats and risks that will exacerbate existing pressures. The present study thoroughly reviewed the recent scientific literature and synthesized existing body of knowledge on the impacts (direct and indirect) of climate change on forest ecosystem services in the Mediterranean Basin. Despite many uncertainties about climate change in the Basin, there appears to be a consensus among a number of studies that climate change is having and will continue to have mostly negative impacts on the Mediterranean forest ecosystem services (wood and non-wood forest products, water resources, carbon storage and recreation and tourism) with possible substantial impacts in the future. Further, evidence is mounting that climate-induced natural disturbances (fires, insect pests, and pathogenic diseases) are becoming frequent and severe. The Mediterranean plants are known for their resilience to natural disturbances. However, the novel climatic conditions may exceed their resilience and alter the ecosystem services. Therefore, there is the need to mitigate the challenges posed by climate change and adapt forest management practices to impending changes to sustain the forest ecosystem services.

Keywords: global change, ecosystem services, forest resources, mediterranean region.

INTRODUCTION

Global forests are changing rapidly in response to a variety of drivers. The earth system is exposed to a broad range of planetary forces that are initiated by human actions, extending from the emission of greenhouse gases to the transformation of landscapes and the loss of biota (Doblas-Miranda *et al.*, 2017). Human-induced global change has accentuated in the second half of the last century (Vitousek, 1994; Steffen *et al.*, 2006). Although several factors have contributed to forest loss and degradation over the years, the one that has gained much attention in the last decades is climate change. The Intergovernmental Panel on Climate Change (IPCC) report shows warming of 0.85 °C (0.65-1.06 °C) from the year 1880 to 2012 by linear trend calculations when the global average data of ocean and land surface temperatures are combined (IPCC, 2014). This trend is primarily due to human-induced increases in concentrations of atmospheric greenhouse gases (GHG), particularly carbon dioxide (CO_2) (Price *et al.*, 2013). According to IPCC (2021) report, carbon dioxide concentration has continue to increase reaching annual averages of 410 parts per million (ppm) in 2019.

The significance of forest ecosystems to human well-being cannot be overstated. The forests provide a wide range of critically important ecosystem services such as climate regulation, biomass production, food, medicines, water supply and purification, pollination, and the provision of habitats for forest species (Bauhus *et al.,*, 2010; Thompson *et al.,*, 2011; Brockerhoff *et al.,*, 2013; Decocq *et al.,*, 2016; Liang *et al.,*, 2016; Mori *et al.,*, 2017). The provisioning of these services undoubtedly makes the forest vital in sustaining human life (Bengtsson *et al.,*, 2000; Foley *et al.,*, 2007). The FAO (2018) report shows that more than 1 billion people including indigenous women depend on the forest for livelihood. The on-going climate change poses a potential threat to the supply of these ecosystem services of the forest. For several agents of global change, climate change has been predicted to drive ecosystems across the threshold (Grimm *et al.*, 2013). Globally, numerous studies have reported the impact of the changing climate on forest ecosystems. For instance, the biome shifts in the Eurasian region (Kicklighter *et al.*, 2014), the changes in the vegetation composition and production, including yellow-cedar decline throughout the coastal-temperate forest region (Hennon *et al.,*, 2006), the increase of the growing seasons of coniferous forest in Northeast China (Xiao-Ying *et al.*, 2013), the decreased spruce growth in boreal Alaska (Barber *et al.*, 2000; McGuire *et al.*, 2010; Beck *et al.*, 2011) and the woody vegetation encroachment into wetlands (Berg *et al.*, 2009).

Climate change impacts on the animal ecology have also been reported such as the modification of the breeding dates of Red squirrels in Yukon in the Canadian boreal forest (Réale *et al.*, 2003; Berteaux *et al.*, 2004), the early arrival dates of migratory birds in New York and Massachusetts (Butler, 2003) and the range reduction of Africa’s most endangered Ethiopian wolf (*Canis simensis*) (Sintayehu, 2018). The forest ecosystems are strongly attached to the climate both directly through the effects of temperature and precipitation and indirectly through the effects of disturbances (Gauthier *et al.*, 2014). Over the years, the forest has adapted continuously to variations in climatic conditions through changes in species composition, vegetation density, and growth patterns (Davis *et al.*, 2005; Carcaillet *et al.*, 2010). However, the current pace and magnitude of the novel climate change are expected to be greater than what forests have been exposed to for years (IPCC, 2001; IPCC. 2007) and may push it down new or unanticipated ecological pathways (Gauthier *et al.*, 2014).

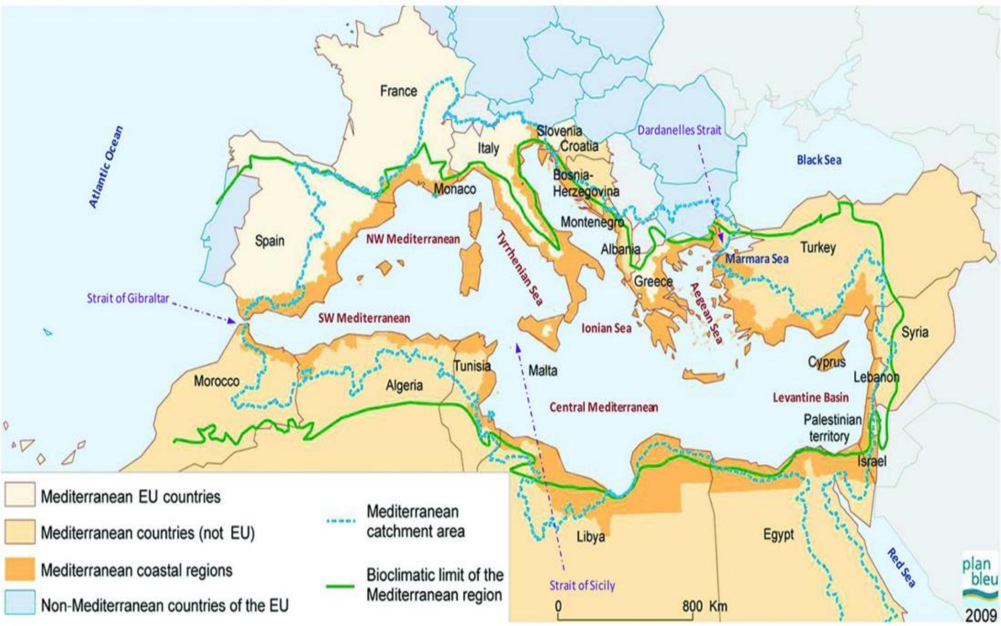
The Mediterranean Basin, which covers more than 2 million square kilometres, is home to a great variety of ecosystems and species. The changing climatic conditions in the region are bringing new threats and risks that will aggravate the existing pressures of the Mediterranean forest ecosystem. The Mediterranean Basin has been identified as one of the climate-change hotspots in the world (Giorgi, 2006). This implies that the Basin will be among the first to face the full impacts of climate change. Therefore there is the need to assess the potential impacts of climate change on the forest ecosystem services in a sensitive area that is likely to become warmer and drier. The main objective of this paper is to present an overview of the impacts of climate change on the forest ecosystem services in the Mediterranean Basin based on a comprehensive review of scientific literature relevant to this study. Specifically, the study sought to answer the following questions. "(i) How has the Mediterranean forest evolved in the light of the changing climate? (ii) Is there any evidence of the effect of climate change on biodiversity? (iii) What are the species that are resilient to climate change, and which ones are vulnerable? (iv) How has climate change impacted the Mediterranean forest ecosystem services? (v) What are the impacts expected in the coming years?

Following this introduction, we structured the review into five major sections. We first discussed the past (observed) and the future (projections) climate in the Basin. We proceeded to discuss the impacts of climate change on biodiversity. We then summarized the scientific literature on climate change impacts on forest ecosystem services. Further, we discussed the indirect impacts of climate change. Finally, we concluded with a summary and outlook of the direct and indirect impacts of climate change on the forest ecosystems services and propose some research directions to improve climate change studies.

THE MEDITERRANEAN BASIN

The Mediterranean Basin (Figure 1) is a meeting point of three continents: Europe, Asia and Africa. The total area is about 2.3 million km^2, with a transition between the arid ecosystems (in North Africa and the Near East) and the temperate forest ecosystems (in the European mountains).

Fig. 1: The Mediterranean Basin. Adapted from Bleu (2009).



The Basin is generally characterised by a mild climate, with warm or hot dry summers and cooler winters (Brochier & Ramieri, 2001). It is not only the largest of the five Mediterranean-type climate regions in the world but also the most geographically complex (with more than 40,000 km of rough coast in different peninsulas and islands) as well as the socio-economically, culturally and politically diverse (Keeley *et al.,* 2011). The Basin is one of the few places on the earth with a long history of intense human activities. Due to the increased exposure to diverse conditions such as political, climate and socio-economic factors for a long time, the area serves as a perfect example of human-environment co-evolution (Thiébault *et al.,* 2016).

Past climate trends (observed) of the Mediterranean Basin

The Mediterranean Basin in time and space provides a wide range of high-quality instrumental time series, documentary information and natural archives, making it suitable for climate reconstructions of past centuries, as well as for the assessment of changes in climate extremes and socio-economic impacts before the instrumental era (Luterbacher *et al.,,* 2006).

Temperature

The spatiotemporal temperature variation in the Mediterranean Basin has been determined using climate reconstructions, ground-based observations, reanalysis and remote-sensing datasets. There is good agreement among these studies that the Basin has shifted towards warmer and drier conditions particularly after the 1980s (Ducrocq *et al.,,* 2016). In analysing the surface air temperature variability and trends over the larger Mediterranean land-area for the twentieth century, Giorgi (2002) using gridded data of New *et al.,* (2000), found a significant warming trend of 0.75 °C (1901–1998), mostly from contributions during the early and late decades of the century with summer showing significant warming. Xoplaki (2002) in a similar study (summer air temperature variability) using regional station-based data for the period 1950–1999 reported a similar trend (0.08 °C/decade). The author found a clear east-west differentiation; over the Balkans and eastern Basin, negative values were observed, although many values were not significant while in the other areas of the Basin, there was a significant warming trend up to 3 °C/50 year. According to Trigo *et al.,* (2006), the warming in these areas did not occur in a steady or monotonic fashion. For example, in the greater part of the western Mediterranean Basin, warming has been reported on two accounts: from the mid-1920s to 1950s and from the mid-1970s onwards (Brunet *et al.*, 2001; Galán *et al.,* 2001; Xoplaki *et al.*, 2003). For the winter trend in the Basin, Giorgi (2002) found slightly stronger warming over the larger Mediterranean land area while Xoplaki (2002) reported a general cooling in the central and warming in the east and west part between 1900-1949 period. Autumn revealed a warming trend in the western Basin and a slight decrease in the eastern sector (Giorgi 2002). In addition to annual and mean variations in temperature, Cherif *et al.*, (2020) reported that climate extremes have also become warmer particularly the severe and frequent waves.

Precipitation

The distribution of precipitation in the Basin shows high spatial and temporal variability. During the beginning of the year (January–August), the continental rainfall accumulates (2–5 mm day^{-1}) while rainfall over the Mediterranean Sea remains lessens. An increase of rainfall is observed over the western Mediterranean Sea in November and over the central and the eastern Mediterranean in December (3–5 mm day^{-1}) (Mehta & Yang, 2008).

Generally, the mean annual precipitation amounts vary from less than 200 mm/year (North Africa, Arabian Peninsula) up to 2,000 mm/year over some northern mountainous terrain (Xoplaki *et al.*, 2004). More intense rainfalls are found in western Mediterranean (5° E), Gulf of Genoa and southern Italy (10–12° E), Eastern Europe and Agean Sea (20–22° E), Cyprus and Black Sea (30° E) (Mehta & Yang, 2008). The Mediterranean precipitation over the decades has displayed a significant trend. A myriad of studies has reported negative trend in different time and space (New *et al.*, 2001; Giorgi, 2002; Philandras *et al.*, 2011). In an earlier study, Piervitali *et al.* (1997) reported that the west-central Mediterranean area experienced a precipitation decrease (about 20 %) during the last 50 years. In an agreement with the findings of Piervitali *et al.* (1997), the IPCC (1998) found a reduction in rainfall by as much as 20 % over the same area. Furthermore, many regional station-based studies also reported a similar decrease in precipitation in the western, central and eastern Mediterranean (Esteban-Parra *et al.*, 1998; Türkeş, 1998; Kadıoğlu *et al.*, 1999; Brunetti *et al.*, 2000; González-Rouco et al., 2001; Tomozeiu et al., 2002; Xoplaki, 2002).

Generally, the Mediterranean precipitation is intense between late autumn and spring (i.e. between October and April) (Trigo *et al*., 2006). In Iberia and central Mediterranean areas, Schönwiese (1993) recorded a negative trend in autumn and spring. Giorgi (2002) found negative winter precipitation trends over the larger Mediterranean land area for the 20th century (1901-1998) using gridded data of New *et al*. (2000). Although there seems to be an agreement on the winter precipitation decline, Philandras *et al*. (2011) found that trends are not uniform and interdecadal variability is high. For example, Jacobeit (2000) reported that in contrast to the prevailing decreasing trend, there was an increase in winter precipitation from southern Israel to northern Libya from 1951–2000. Trigo *et al*. (2006) pointed out that caution must be exercised when analysing precipitation trends as it critically depends on the length of time-series analysed. According to Price *et al*., (2013), detecting changes in seasonal and annual precipitation patterns is a challenging task because precipitation is intrinsically more variable than temperature, both in time and space.

Future climate (projections) of the Mediterranean Basin

Until 1990, numerous studies used global-coupled climate models to assess the potential climatic change in Europe. Out of these studies, only a few included the Mediterranean region (Ulbrich *et al.*, 2006). The use of climate models in projecting changes in climatic conditions in the future is not without challenges. The main areas of uncertainty with models projections particularly the Global Circulation Models (GCMs) are clouds and their radiative effects, the hydrological balance over land surfaces, and the heat flux at ocean surfaces (Price *et al*., 2013). However, despite these limitations, climate models such as GCMs capture current expert knowledge of global meteorology and have proven to be an essential tool for the assessment of the effects of simulated changes in the accumulations of Green House Gases (GHGs) and other atmospheric pollutants (Price *et al.*, 2013).

Temperature

Numerous research studies have used different climate scenarios to project the future temperature changes in response to the GHGs emissions in the Mediterranean Basin. According to Lionello *et al.* (2006), the Basin probably remains one of the few places where most predictions give comparatively consistent climate change signals. The comprehensive climate report of Cherif *et al.* (2020) shows that the current Mediterranean Basin-wide annual mean temperatures stand at 1.5 °C. Over land regions, significant warming of the range of 0.9-5.6°C (NEAR: 2020-2039, MID: 2040-2059, END: 2080-2099) for the future has been projected by the EURO-CORDEX regional simulations (with regards to the reference period

1980-1999) (Cherif *et al.*, 2020). Warming is expected to be milder in winters and much stronger during summers. This is generally linked to land-atmosphere interactions and the shift to drier conditions (Seneviratne *et al.*, 2006; Jaeger & Seneviratne, 2011; Quesada *et al.*, 2012; Zittis *et al.*, 2014). For business-as-usual scenario, the studies of Lelieveld *et al.* (2016) and Sillmann et al., (2013) show that the summer daily maximum temperature will rise to 7 °C at the end of the 21st century. Daytime temperatures are expected to increase more than night-time temperatures, signifying an increase of the amplitude of the diurnal temperature range (Lionello & Scarascia, 2018). Moreover, changes in the occurrence of extreme events are expected to closely follow changes in the inter-annual variability (Cherif *et al.*, 2020).

Precipitation

Generally, there are several uncertainties with precipitation projections. This is because precipitations variations are more difficult to predict than temperature changes and projections are mostly with low confidence (Cherif *et al.*, 2020). In the Mediterranean Basin, GCMs and Regional Climate Models (RCMs) have been used for future precipitation projections. Déqué *et al.* (1998) using the GCM model (ARPEGE) predicted 30 % increase in winter precipitation over the northern Mediterranean. Sánchez *et al.* (2004) projected 20 % increase in winter precipitation for 2071-2100 period in the western and northern parts of the Mediterranean using the RCM model (HadAM3H) but in the southern parts, there were reductions (about 10 %). Different models show different sensitivities over the Mediterranean Basin. According to Brochier & Ramieri (2001), GCMs are not able to represent regional and local climate patterns accurately because of their coarse spatial resolution. Therefore their dependability declines moving from the global to the regional and to the local scale as well as moving from the annual, to the monthly and to the daily scale. For summer projections, almost all the models (GCMs and RCMs) predict reduction typically in the range of 10–40 % for the future (Déqué *et al*., 1998; Sánchez *et al*., 2004; Cherif *et al*., 2020). Concerning spring and autumn projections, Palutikof *et al*. (1999) using statistical downscaling found a decrease (around 20 %) in spring over the central Mediterranean and in autumn over a large part of the Basin by 2099. The only exception was North Africa, where autumn precipitation is expected to increase (20-30 %). Overall, while it is reasonable to believe that precipitation will likely decrease in the Mediterranean Basin, assigning quantitative values, especially at sub-regional scale is very challenging (Cherif *et al*., 2020).

IMPACT OF CLIMATE CHANGE ON BIODIVERSITY

Harbouring native flora and fauna and conserving biodiversity remain the key ecosystem services of the Mediterranean forest (Noce & Santini, 2018). The Mediterranean forests shelter diverse plants and animal species. It provides habitat for over 25, 000 plant species, of which 60 % are endemic (13,000 species) (Myers *et al*., 2000; Thompson *et al*., 2005; Vié *et al.*, 2009). A number of these species are flagship species. For example the cedar tree (*Cedrus libani*), argan tree (*Argania spinosa*) and the date palm of Crete (*Phoenix theophrasti*). A typical Mediterranean forest consists of broadleaved species (mainly oaks), both evergreen and deciduous, such as *Quercus ilex*, *Q. suber*, *Q. coccifera*, *Q. pubescens*, *Q. cerris*, *Q. pyrenaica*, *Q. toza*, *Q. calliprinos*, Q. *ithaburensis* and conifers such as *Pinus halepensis*, *P. brutia*, *P. pinea*, *P. pinaster* and *Juniperus species* (Plan Bleu, 2013). Climate change has emerged as a potential threat to biodiversity in the region. It is evident that the changing climate has already affected a broad range of organisms with diverse geographical distributions (Hughes, 2000; Wuethrich, 2000; McCarty, 2001). Literature outputs show that many species have shifted their geographic ranges, generally toward higher elevations in response to the novel climatic conditions (Burrows *et al.*, 2011; Chen *et al*., 2011; Doney *et al*., 2012). The Atlas cedar (*Cedrus atlantica*) in Morocco for example has moved upwards and invaded the distribution area of juniper species (*Jeniperus thurifera*) (Benzyane *et al*., 2010). Similarly, in Montsensy Mountains in Spain, Penuelas and Boada (2003) found that due to 1.4 °C increase in temperature, holm oak (*Quercus ilex*) has gradually replaced European beech (*Fagus sylvatica*) and heather (*Calluna vulgaris*) heathlands at medium altitude (800–1400m). Although there is growing evidence of climate change impacts on species range, Price *et al*., (2013) highlighted that it remains uncertain as to what extent the populations of individual tree species will be able to migrate naturally with shifts in suitable climate zones.

In tracking changes in the ecology of species due to climate change impact, Walther *et al*., (2002) pointed out that the timing of seasonal activities of animals and plants is probably the easiest approach to adopt. The changes in the phenology of plants, for instance, can directly provide evidence for regional climate change, especially for global warming (Lu *et al*., 2006). Assessing the evidence of olive pollination date variations in relation to spring temperature trends in Italy, Bonofiglio *et al*., (2009) found that the start, full and end of flowering dates of olive trees had an advance trend of 6, 8 and 10 days respectively which significantly correlated to the increase of mean temperature (12.2 °C in 1985 and 14.9 °C in 2007).

On animal ecology, changes in phenology due to climate change have been reported. Birds and butterflies, in particular, have received global attention (Walther *et al*., 2002). The evidence assembled by Peñuelas *et al*., (2002) in the Mediterranean Basin reveals that butterflies appear 11 days earlier while spring migratory birds arrive 15 days later than in 1952 in a study to assess the first long-term (1952–2000) evidence of altered life cycles for some of the most abundant Mediterranean plants and animals species. On bird’s phenology, at 9 out of the 23 sites across Europe (including the European Mediterranean), Both *et al*., (2004) reported earlier egg-laying dates for the pied flycatcher (*Ficedula hypoleuca*). According to Visser *et al*., (2006), the declining populations of pied flycatcher was due to a mismatch between nesting dates and the earlier emergence of their major insect prey. Common bats (*Pipistrellus kuhlii*) offer a unique opportunity to explore the relative effects of climate change on species distributions due to their versatile ecology and synurbic habits. Ancillotto *et al*., (2016) reported that in the last four decades, the species has expanded its geographical range by about 394 %, a process the authors attributed primary to extant climatic changes. Climate models projection further suggest that the Mediterranean forest ecology and communities will be strongly modified by climate change, probably causing both direct and indirect effects on individual species. For example, Soultan *et al*., (2019) predicted that about 17 % of the endemic mammals in the Afro-Arabian region under the current climate change scenarios could become extinct before 2050. In conclusion, evidence is mounting that climate change is altering species distributions, physiology and other life cycle events triggered by environmental signals. The changes in physiology, phenology and distribution of individual species will inevitably alter competitive, and other, interactions between species, with consequent feedbacks to local abundance and to geographic ranges (Hughes, 2000).

IMPACTS OF CLIMATE CHANGE ON FOREST ECOSYSTEM SERVICES

Ecosystem services are the benefits humans derive from the ecosystem. They preserve human existence through their species and natural supporting systems (Daily, 1997).

Therefore, climate change impacts on species, populations, and ecosystems affect the availability and supply of ecosystem services including changes to provisioning, regulating, supporting and cultural services (Weiskopf *et al*., 2020). In this review, we focused on the impacts of climate change on wood and non-wood forest products, water resources, carbon storage and recreation and tourism in the Mediterranean Basin.

Wood and non-wood forest products

The main provisioning services of the Mediterranean forest ecosystem are wood products (roundwood, sawnwood, wood-based panels, wood pulp, paper and paperboard and fuelwood) (FAO, 2013). Economically, the supply of these products supersedes all other provisioning services (Vizzarri *et al*., 2017) as these products are easy to quantify. The changing climatic conditions are expected to have impacts on timber provision in the Mediterranean Basin. Yet, studies on climate change impact on wood production are scarce. Moreover, climate change impacts on the regional timber markets are lacking. Peñuelas (2018) found the reduction of stem growth and high stem mortality in long-term field experiments that combined experimental drought and natural extremes. Coupled with water scarcity and high water demand in the region, many tree species (Holm oak, Aleppo pine and Maritime pine) are expected to decline (Sabaté *et al*., 2002; Schröter *et al*., 2005). The Mediterranean forest ecosystem is not only known for the supply of wood products but also Non-Wood Forest Products (NWFPs). For instance, Croitoru (2007) documented cork, fodder, mushrooms, honey and others (berries, medicinal plants, pine nuts, chestnuts, etc.) as the major NWFPs in the Mediterranean forest ecosystem. The supply of these products is essential to the local population. In the rural settings for example the collections of wild products are ways of providing nutritional needs for people of limited means (Sánchez-Mata & Morales, 2016). According to Tukan *et al*., (1998), vegetables collected from the wild are sources of vitamins, omega-3 fatty acids, polyunsaturated fatty acids, minerals, antioxidants, and fiber (Huss-Ashmore & Johnston, 1994; Zeghichi *et al*., 2003) at a time when garden vegetables are not yet ready to be harvested and no fresh fruits are available. The report of Bleu (2019) shows that mushrooms, olive and carob supports local economies by contributing raw materials to industries, which in turn protect jobs in these sectors.

Corks are produced from the bark of *Quercus suber* L. trees, usually called cork oaks, which are found in the Western Mediterranean countries (Portugal, Spain, Algeria, Morocco, Italy, Tunisia and France) (Dickerson, 2014). Cork is used for cork stoppers, coverings and flooring, composites, and insulation (Jruivo, 2016). Of all the cork products, the cork stopper has the highest added value. The cork stoppers drive the cork industry representing almost 70 % of the cork market value (WWF, 2006). In Portugal alone, cork constitutes around 900 million Euros in the country's exports, every year (Jruivo, 2016). In the Iberian Peninsula in Spain, the cork sector employs 34,654 people out of whom 22,032 are in industrial jobs, and 12,622 are in the cork harvesting companies (WWF 2006). Climate-induced droughts are severely impacting both the quantity and quality of the cork produced (Jruivo, 2016). The report of Dickerson (2014) shows that cork oaks have been growing thinner and more porous bark layers. According to Teixeira *et al*., (2014), cork producers prefer bark that is at least 27 millimetres (1 inch) thick to make a good cork, but most of the trees are currently producing bark between 3 mm and 10 mm (0.1 inches and 0.4). The current climate if continues is likely to pose a significant threat to the cork industries (income generation and sustainability) in the western Mediterranean countries, although the direct assessment of the impact of climate extremes on the economic and social factors in the cork producing countries has not been attempted due to the lack of data and several uncertainties (Lei, 2010).

Apart from cork, mushrooms are considered as one of the most important NWFPs, with growing economic value in many rural areas of the Mediterranean region (Büntgen *et al.*, 2015). The role of precipitation as a limiting resource controlling mushroom growth, diversity and distribution has been reported by multiple studies (Salerni *et al.*, 2014; Alday *et al.*, 2017a; Alday *et al.*, 2017b; Herrero *et al.*, 2019). In assessing 48,348 mycorrhizal and saprotrophic fungal fruit bodies that were recorded at weekly intervals between 1995 and 2013 in Pinar Grande, Büntgen *et al.*, (2015) found that the mean annual number of sporocarps dropped from 2,880 to 2,045 while mean species richness declined from 55 to 51. The authors linked the trends in the phenology and productivity to the decreasing July–September precipitation totals. In conclusion, while it is reasonable to believe that climate change will modify wood production; little evidence exists on its significant impact in the Basin. On the other hand, non-wood forest products such as cork and mushrooms seem threatened by climate change, a situation that is likely to affect cork industries and the rural population in the Basin, especially in the southern and the eastern rims that depend on these resources for livelihood.

Water resources

The forest protects the soil, regulates the water cycle and accommodates most of the earth's biodiversity (Millennium Ecosystem Assessment, 2005). In the Mediterranean Basin, the forest ecosystems help to minimise flooding, recharge water aquifers, purify water bodies and regulate runoff and surface water flow through canopy interception (Mavsar *et al.*, 2013; Noce and Santini 2018). Water constitutes an essential resource in the Mediterranean region. According to the UNEP/MAP (2017) report, only 3 % of the world's freshwaters are found in the Mediterranean Basin. These resources are unevenly distributed over space. The studies of Milano *et al.*, (2013) show that 50 % of the water resources are found in Italy and Greece and 25 % in France and Turkey catchments. The southern and eastern catchments account for only 4 % and 2 % respectively (FAO, 2010a). The unequal distribution of water resources is reflected in the water availability per capita (Falkenmark *et al.*, 1989). For instance, in the northern catchments, people have access to more than 1700 m^3 $capita^{-1}$ $year^{-1}$, which places them fairly in a secure situation while in the southern and eastern catchments, about 180 million people are considered water poor (<1,000 m^3 $capita^{-1}$ yr^{-1}) and 80 million people suffer from extreme water shortage (<500 m^3 $capita^{-1}$ yr^{-1}) (MedECC, 2020). In spite of the scantiness of water resources in the Basin, climate change is having and will continue to have impacts on the various hydrological components (runoff, groundwater recharges, and river aquifers), which will further aggravate the water crisis in the region. In an attempt to assess the potential impacts of climate change on water resources in Lebanon (eastern Mediterranean), Shaban (2009) reported the decline of rivers and groundwater (23 % and 29 % respectively) over the last four decades. Similarly, on the southern shore (North Africa), an area that is often considered a "climate change hotspot" (Diffenbaugh & Giorgi, 2012), Ghenim & Megnounif (2013) found that due to precipitation decline, water flow reduced from 37 % to more than 70 % from the east to the west of Algeria.

Besides studies (observation) reporting on climate change impacts on water resources in the Basin, several Mediterranean countries have made an effort to assess the climate-induced changes that are likely to occur in the water system. For example, in Spain, an increase in annual mean temperature by 1 °C may lead to a decline of 5 to 14 % in water harvest. Moreover, a temperature increase of 4 °C could result in a high decline of about 22 % in water harvest in some areas (Moreno-Rodriguez, 2005). In Lebanon, the government estimates show that climate change will cause water loss up to 350 million m^3 in 2050 (Khawli, 1999). In addition to the above projections, future scenarios also point to a significant reduction of snow accumulation, water yield, runoffs, surface water flow and freshwater availability (Table 1).

Table 1: Hydrological models predicting the impacts of climate change on hydrological variables in the Mediterranean Basin

Country/Region	Hydrological variable	Reduction %	References
Mediterranean Basin	Freshwater	20	Ludwig et al., (2009)
Spain	Runoff	10-30	Estrela et al., (2012)
Israel	Stream flow	11 and 16	Givati et al., (2019)
Western Mediterranean	Runoff	2-77	Ruelland et al., (2015)
Morocco	Surface runoff	19-63	Marchane et al., (2017)
Tunisia	Annual inflow	37	Allani et al., (2019)
Algeria	Surface water flow	20-25	Elmeddahi et al., (2014)
Spain	Drinking water	3-49	Bangash et al., (2013)
Italy	Snow accumulation	82-92	Senatore et al., (2011)
Spain	Water yield	11.5 and 44	Marquès et al., (2013)
Turkey	River discharge	12	Chenoweth et al., (2011)
Mediterranean Basin	Freshwater resources	30–50	Milano et al., (2013)
Algeria	Rainfall	13 and 25	Elouissi et al., (2017)
France	Water discharge	20	Lespinas et al., (2010)
Mediterranean Basin	Surface water	20	Mariotti et al., (2008)
Mediterranean coastal rivers	Water discharges	26 and 54	Lespinas et al., (2014)
Tunisia	Runoff	25 and 48	Sellami et al., (2016)
Jordan	Water resources	22	Chenoweth et al., (2011)
Algeria	Annual stream flow	1.18	Elmeddahi et al., (2016)
Spain	Water resources	15-30	Marianne et al., (2013)

Thus, it can be deduced that water available for tree growth will be impacted which will affect forest productivity in an ecosystem currently under high water stress.

Carbon storage

The world's forests store over 650 billion tons of carbon in various components: 44 % in biomass, 45 % in soil and 11 % in deadwood and litter (FAO, 2010b). The regulation of the climate at the local, regional and global levels by the forest through biophysical processes associated with evapotranspiration, albedo and roughness has long been recognized by scientists (Noce & Santini, 2018).

The Mediterranean forest ecosystem contributes immensely to carbon sequestration, which helps regulate the climate both at the regional and global levels. The forest ecosystem has been estimated to sequester carbon (aboveground and belowground) between 0.01 and 1.08 t C ha^{-1} annually (Croitoru & Merlo, 2005). However, the novel climatic conditions are likely to disrupt the rate of carbon sequestration of the forest ecosystem. For example, holm oak is a dominant species in the Mediterranean Basin but the current climatic shift has increased defoliation and mortality of the plant species (Liu *et al.*, 2015). The decline of productivity due to increased defoliation and mortality could impair carbon storage. Peñuelas *et al.*, (2017) in their milestone studies predicted that tall grass that is well-adapted to the current change in climate could partially displace holm oak if the climate becomes drier, leading to a sharp decline of the carbon sequestration in the region. Ideally, forest carbon reservoirs may be affected by major changes in mortality and growth rate associated with climate and forest structure and their interactions. (Van Mantgem *et al.*, 2009; Dietze & Moorcroft, 2011; Ruiz-Benito *et al.*, 2012).

A myriad of studies has shown that increased atmospheric CO_2 (CO_2 fertilization) could increase tree growth and subsequently enhance carbon sequestration especially in the temperate region (Cao & Woodward, 1998; Ciais *et al*., 2008; Bellassen *et al*., 2011). On the contrary, these positive gains could be suppressed in the Mediterranean region due to the increasing climatic variability and extreme weather events such as frequent and intense drought (Ciais *et al*., 2005; Zhao & Running, 2010; Hoch & Körner, 2012). Prolonged drought is a common phenomenon in the Mediterranean Basin (Seguí *et al*., 2016). These droughts have severe impacts on forest growth and productivity. In the last 30 years, Allen *et al*., (2010) claimed that forest dieback has multiplied 3 to 4 times in the region.

Drought stress and tree mortality according to Williams *et al*., (2013) are controlled by temperature variations. The studies of Amthor (2000) show that temperature increase could influence carbon sink because carbohydrate utilization which controls cellular metabolism (respiration) is closely associated with temperature. In summary, the net carbon balance and the rate of carbon sequestration in the Mediterranean forest ecosystem seem vulnerable to climate change particularly, climate-induced disturbances such as prolonged droughts and severe fires which are becoming rampant.

Recreation and tourism

The Mediterranean forest landscape offers multiple amenities that include a wide range of social, spiritual, cultural and historical services linked to the structural complexity and scenic beauty of the forest composition (flora and fauna) (Mavsar *et al*., 2013). The aesthetic view of the forest landscape has long been appreciated and the demand for its services has been rising speedily due to urban expansion, financial growth and accessible transport (Mavsar *et al*., 2013). The coastal areas of the Mediterranean Basin are also among the world's leading tourist centres and primary sources of income and employment in the region (Brochier & Ramieri, 2001). In 2003, the Mediterranean countries received 147 million tourists and generated US$113 billion (Giannakopoulos *et al.*, 2005). In 2007, about 275 million tourists visited the Mediterranean countries. According to Mavsar & Varela (2010) the six natural parks in Spain alone received about 1.6 million visitors in 2008, which further increased by 40 % in the last ten years.

Despite the boost the tourism business has received over the years, the future of Mediterranean tourism remains uncertain with the changing climatic conditions. Wheeler (1995) in an earlier study showed how climate-induced drought in Spain caused island resorts like Majorca in Spain to depend on water being transported from the mainland amid political tensions. Apart from drought, the increasing heat waves as has been reported by a number of studies are likely to make the Mediterranean Basin less attractive to tourists in the future (Perry, 2001; Trigo *et al.*, 2005; Lionello *et al.*, 2006). Perry (2001), was among the earlier researchers to have reported the increasing frequency of heat waves in the Basin. The author found that short-duration heat waves (3-5 days) happened 33 times in the central Mediterranean alone from 1950-1995. In a follow-up study, Conte *et al.*, (2000) found that between the periods 1950-1959 to 1980-1989, individual heat wave days rose from 52 days to 230 days. Heat waves cause health-related issues. For instance, the 45 deaths linked to heat in Cyprus were recorded when the maximum temperature exceeded 40 °C on 8 successive days (Perry, 2001). Recent studies show that heat waves have not only become frequent but more severe (Ziv *et al*., 2005; Baldi *et al*., 2006; Linares *et al*., 2020; Molina *et al*., 2020). In August 2003, northern Mediterranean countries (southern Europe) experienced a record-breaking summer temperature. According to Trigo *et al*., (2005), the heat wave that occurred between the 1st and the 15^{th} of August contributed to excessive mortality rates throughout Europe, with a deadly impact in France. In general, Mediterranean tourism activities are at the crossroads due to the on-going climate-induced changes (frequent droughts, beach erosion, severe fires and extreme heat waves). Considering the climate models projection, the industry could face a variety of new risks.

INDIRECT IMPACTS OF CLIMATE CHANGE

In addition to the direct impacts of climate change on forest ecosystem services, there are several natural disturbances that climate change may aggravate to alter the ecosystem services of the Mediterranean forest. One of the disturbances climate change could influence is the insect population. Climate-induced drought can weaken plants and make them vulnerable to phytophagous insects (Jaworski & Hilszczański, 2013). Drought stress has been found to decrease tree resistance to bark beetle infestation in spruce and pine forest (Cobb *et al*., 1997; Berg *et al*., 2006). Bark beetles cause huge loss to conifer forests worldwide. In the Mediterranean Basin, about 40 species of bark beetles live in conifer trees. These ectothermic organisms are sensitive to changes in temperature. An increased temperature can cause earlier spring flight and hastens larval development of local populations which can lead to frequent and large-scale outbreaks and damage to tree species (Lieutier *et al*., 2016).

Due to their high genetic variability, short life cycles, mobility, great reproductive potential, and physiological sensitivity to temperature, a number of insects can react swiftly to environmental variation (Andrewartha & Birch, 1954; Ayres & Lombardero, 2000). A good example is the range expansion of pine processionary moth (*Thaumetopoea pityocampa*) affecting a number of tree species that were previously not accessible to this insect. Several experimental and modelling approaches have demonstrated how climate warming has lowered climatic barriers to its expansion towards higher latitudes and elevations (Battisti *et al*., 2005; Roques *et al*., 2015). According to Lieutier & Paine (2016), the Mediterranean endemic insect species, which currently do not cause any harm could benefit from temperature rise, tree weakening, presence of new host species and alteration of the forest composition to increase their population and become pest species. Besides insects' invasion, climate change may accelerate the susceptibility of plants to pathogenic attacks. In their studies, De Luís *et al.*, (2001), reported that climate-induced floods have created a conducive atmosphere for pathogen invasion of the oak forest.

Another significant disturbance that climate change is expected to exacerbate is fire occurrence. Historically, fire data clearly shows that changes in wildfire occurrences are associated with climate change (Fried *et al*., 2004). Multiple fire studies over the years have reported that fire frequency (Clark, 1988; Brown & Swetnam, 1994) and area burned (Flannigan & Wagner, 1991) correlated with air temperature, raising serious concern on the potential impacts of climate change on wildfire severity. In the Mediterranean Basin, humans have lived with fire and used it for agricultural and rural activities for millennia. However, in the last mid-century, there has been an increase in the number of ignition sources, causing a surge in fire risk and uncontrolled fires (Schelhaas *et al*., 2003; González & Pukkala, 2007; San-Miguel-Ayanz *et al*., 2013). Although several factors contribute to the increase in fire events, De Dios *et al*., (2007) explained that climate change could be a major contributor, as changes in daily temperature and relative moisture content alters vegetation growth, fuel structure and burning pattern.

Dryness and high temperatures can intensify favourable conditions for fires to burn large areas (Conte *et al*., 2000). Certini (2005) and Rulli *et al*., (2012) reported that the increase in fire occurrence may expose forest soil to erosion due to accelerated hydrophobicity. This will inhibit plant regeneration (Delitti *et al*., 2005) leading to increased desertification in areas already affected by drought. The studies of Thornes (1988), show that beneath 30 % vegetation cover, plants may not be able to hold soil particles and will cause the soil-plant system to degrade. Further, the increased fire events may pose a severe threat to the new plant growth after heavy rainfall due to nitrogen and soil loss (De Luís *et al*., 2001). This could trigger the transition of forestland to shrubland and bushland most importantly areas near sub-desert zones and steppes (De Dios *et al*., 2007). In France, the turnover of fires has been predicted to change from 72 years (present average) to 62 years by 2100 particularly in forested areas while at maquis shrubland, it is estimated to change from 20 to 16 years (Lieutier & Paine, 2016). This according to Nageleisen *et al*., (2010) will make the natural restoration of the forest not possible in several instances and will probably lead to a huge loss of forest lands in the Mediterranean Basin.

UNCERTAINTIES IN DATA SOURCES

Climate change and its accompanying uncertainties are of grave concern to natural resource managers (Nichols *et al*., 2011). Understanding uncertainty remains a major issue in the scientific community. This is because it affects many critical issues facing the world- from climate change prediction to economic modelling, to interpretation of medical data (Katz, 2002). In this section, we attempt to discuss uncertainties in the data sources we have reviewed. In the studies reviewed, one major source of uncertainties identified was measurement errors. This occurs when measuring an unknown physical constant. According to Katz (2002), it is unavoidable that such errors happen, including those of a random nature whose magnitude reflects the precision of the instrument on which the measurements are based and those due to systematic error (e.g. miscalibration of instruments sometimes called a source of 'bias'). Another area surrounded by uncertainties is climate models projection.

For example, on precipitation projections in the Basin, while the number of models projects decreases in the future, the magnitude and pattern of decrease vary widely across models. The uncertainty in projections is even larger at the local scale because of the influence of local forcings, e.g., topography and coastlines (Cherif *et al*., 2020). In addition to temperature and precipitation projections, greater uncertainties exist in studies that use climate envelope (CE) models (models describing relationships between species occurrences and bioclimate variables) and species area modelling to predict future changes in species composition and distribution. According to Price *et al*., (2013), these studies cannot fully account for multiple and often synergistic factors (e.g. predation, herbivory and mutualism) that influence ecosystem assembly making model projections of future species distributions less robust".

CONCLUSION

Globally, climate change has received much attention due to its impacts on earth processes sustaining human life, such as the forest ecosystems. Climate change impacts in the Mediterranean Basin are of much interest as the Basin has been described as a climate change hotspot. In this review, we have assessed the impacts of climate change on the Mediterranean forest ecosystem services. In essence, the Mediterranean forest is currently undergoing profound, sometimes irreversible changes with impacts on the ecosystem services. An increasing number of studies have reported mostly negative impacts of climate change on biodiversity, wood and non-wood forest products, water resources, carbon storage, recreation and tourism with future projections showing severe impacts. Furthermore, climate-induced natural disturbances have also been increasing. Forest fires are becoming rampant while insect pests and disease infestations are expanding causing large-scale forest damage and ecosystem disturbances. Although there are several uncertainties about climate change, the ample evidence far exceeds the myths surrounding it. In the Mediterranean Basin, considerable efforts have been made in the areas of model projections and the identification of climate risks and opportunities; nevertheless, there are still missing links. For example, the capacity of species and populations to adapt to climate change is least studied, despite its relevance in forecasting persistence under future environmental conditions (Donelson *et al*., 2012). Moreover, the synergistic effects of climate change and other drivers of change (land use and pollution) on the forest ecosystem services have not been significantly addressed. Furthermore, the large-scale impact of climate-induced natural disturbances in the Mediterranean forest ecosystem is scarce. More studies need to be conducted for clarity in these areas, particularly in the understudied ecosystems (southern and eastern Mediterranean rims) threatened by desertification, evidence of ecosystem depletion.

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CONFLICTS OF INTEREST

The authors declare there are no competing interests.

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