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Implications of forest definition for quantifying disturbance regime characteristics in Mediterranean forests

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Abstract

In the context of climate change and the increasing incidence of extreme events, global-scale assessments of forest disturbance regimes are needed to monitor changes, inform decision-making and adjust management and planning. But estimations of disturbance regime parameters can be strongly influenced by the criteria used for defining what constitutes a forest. Forests in Mediterranean regions are subject to increasingly higher pressure from climate change and anthropogenic factors. These pressures take the form of slow and diffuse degradation processes, such as drought-induced mortality and competition with shrubs, but also sudden stand-replacing disturbances, such as fire. Many Mediterranean forests, composed of widely spaced trees, are at the lower limit of the 10% canopy cover threshold set by the FAO for defining *forests*, while others are highly fragmented and mixed with a bushy matrix, qualifying them as *other wooded lands*. We thus expect assessments of forest disturbance regimes in the Mediterranean region to be particularly sensitive to the thresholds chosen. We assess the uncertainty linked to using different forest definitions for calculating disturbance rotation periods for the 40 ecoregions composing the Mediterranean biome. Using Google Earth Engine and remotely sensed data between 2000-2015, we apply different criteria for calculating the extent of forests and the areas disturbed within them, accounting for forest type, minimum size, canopy density and land use change. We identify the ecoregions with the disturbance rotation periods that are the most sensitive to these different definitions and compare the overall uncertainty with other major forest biomes. We conclude by discussing the importance of identifying harmonized definitions that can best support the sustainable management of Mediterranean forests, as well as opportunities for making consistent and accurate global baselines that can help improve projections of climate change impacts.

Keywords: Forests, Disturbances, Remote Sensing, Planning, Climate Change

Introduction

Sustainably using and managing forests require that we understand not only their current state, but also the dynamics that lead to this state (Kuuluvainen et al 2021). In fact, disturbance events are one of the key drivers of forest change, and with the ongoing global environmental change, their magnitude and intensity are increasing in many parts of the world (Seidl et al 2014, Coop et al 2020). This calls for a global assessment of forest disturbances that goes beyond the identification of disturbance areas (Hansen et al 2013) and their major driving agents (Curtis et al 2018), to quantify disturbance regime characteristics and monitor their changes over space and time. Such an assessment is particularly helpful for identifying areas of fast changes and planning appropriate adaptation and mitigation measures. However, estimations of disturbance regime metrics are likely strongly influenced by the criteria used for defining what constitutes a forest. In particular, deciding which thresholds to use with these criteria can be challenging for global-scale assessments when forests in certain biomes are highly fragmented or their boundaries with other vegetation types are gradual and not clearly delimited. This is the case in the Mediterranean biome.

Forest definitions differ between countries and institutions depending on geographical, ecological, economic or political considerations (FAO 2018). Some global-scale studies use remote-sensing-based forest delineation methods that may not be consistent with conventional definitions for international reporting, such as those established by the FAO (Sexton et al 2016). The FAO defines forests as lands not primarily used for agricultural or urban purposes, spanning more than 0.5 hectares, and covered by trees taller than 5m with a canopy cover denser than 10%, or able to reach these thresholds *in situ* (FAO 2020). The FAO places tree formations that have the canopy density criterion between 5-10% for trees only, or 10% for trees, combined with shrubs and bushes, under the class *Other wooded lands*. Those that do not meet the area and land use criteria fall under the *Trees Outside Forests* category.

The Mediterranean climate is characterised by hot and dry summers and cool and wet winters (Köppen 1936; Peel et al 2007). The vegetation that thrives under this climate constitutes the Mediterranean biome. The latter occurs across the five major realms of the world (Palearctic, Afrotropic, Nearctic, Neotropic and Australasia), essentially in the semi-arid areas transitioning between temperate and dry lands (Dinerstein et al 2017). Most Mediterranean regions are considered hotspots for biodiversity (Myers et al 2000). Many of these ecosystems are subject to seasonal drought and wildfire and are populated by woody species adapted to water and heat stresses (Peñuelas et al, 2017). For examples, some Mediterranean tree species have a thick insulating bark, such as *Quercus suber*, while others need fire for seed germination, such as *Eucalyptus* species. Also, many Mediterranean forests and woodlands have an open canopy, sometimes combined with a rich and extensive short shrub/bush understory. This is notably the case of cork oak woodlands, which harbour rich understory communities (Santos et al 2016). Other Mediterranean forests and woodlands are highly fragmented, as shaped by centuries of interactions with humans, mainly through industrial harvest, grazing, conversion, plantations, and afforestation (FAO 2018). This is notably the case in the Mediterranean basin, where forests are an integral part of the human-dominated landscapes. There, scattered trees may be naturally regrowing on abandoned lands (Vilà-Cabrera et al 2017) or may be mixed with pasture, as part of agroforestry systems or because of degradation processes (e.g. seasonal fire, overgrazing and bush encroachments) (Acácio et al 2009).

Under FAO's definition for forests, some tree systems in the Mediterranean biome, like the oak woodlands, are at the lower limit of the thresholds set for canopy cover and forest area, which may qualify them as *Other wooded lands* or *Trees outside forests* (FAO 2018). In addition, mapping global forest cover is mainly based on the classification of satellite imagery and the higher spectral reflectance from the undergrowth layer and bare soil are factors that can lead to misclassifications (Bastin et al 2017). This can be problematic for quantifying and comparing disturbance regime characteristics across regions. We thus expect Mediterranean forests to be highly sensitive to these biophysical thresholds.

Here we examine the ecoregions in the Mediterranean biome where forests, woodlands and shrublands are less clearly demarcated and assess the uncertainty linked with using different forest and disturbance definitions for calculating forest disturbance rotation periods. Our aim is to identify those ecoregions that have the highest uncertainty to forest definition and compare the overall uncertainty in the Mediterranean biome with other forest-dominated biomes.

Methodology/approach

We use Google Earth Engine (Gorelick et al 2017) to calculate the total areas of forests and disturbances and derive the associated disturbance rotation periods. We conduct the statistical analysis and plotting using R (R Team 2021). We consider the 40 ecoregions classified as *Mediterranean Forests, Woodlands & Scrub* within the *Ecoregions* data product (Fig 1) (Dinerstein et al 2017). We use the Global Forest Change (GFC) tree cover 2000 dataset (Hansen et al 2013) as baseline for delineating forest patches and aggregating their areas by ecoregion. Only vegetation that are taller than 5m are considered as trees in this dataset. Consequently, regenerating forests that were not covered by trees in 2000 are not included even if they comply with the FAO's definition.

We use the tree cover loss dataset for aggregating disturbance areas that occurred within these forest areas. We focus only on the period 2001-2015 (count of 15 years) and exclude the years beyond to avoid inconsistencies in the GFC product following changes in both Landsat satellite sensor and loss detection algorithm (Palahi et al 2021). We use ESA land cover CCI (Defourny et al 2017) to exclude agricultural and urban tree cover, as well as loss due to land use change (lands that were dominated by natural vegetation in ESA land cover 2000 and becoming cropland or urban areas in 2015).

We set our forest definitions by changing the canopy density, minimum forest area and forest classes, while complying with the criteria of FAO and ESA definitions (Table 1). We term forest a land covered by trees up to the thresholds set by the definitions for canopy density and area covered, and where relevant, not classified as urban or agricultural lands (ESA definition). We consider disturbances as those events that lead to the abrupt removal of stands of trees, thereby being represented as loss pixels in the GFC product. These include both natural processes (e.g. wildfire) and anthropogenic activities allowing tree regrowth (e.g. harvest). For each forest definition, disturbances are calculated only within the areas considered as forests. Both forest and disturbance areas are aggregated within each ecoregion. We consider disturbance rotation periods (expressed in years) as the time for a forest area to be disturbed again entirely and calculate it as the entire forest area divided by the annual disturbance area (Pugh et al 2019). We quantify the uncertainty due to forest definition by calculating the standard deviation among the rotation periods calculated with each definition and then dividing by the mean rotation period. The coefficient of variation obtained (expressed in %) allows us to compare standardized variability among ecoregions which may have distinct disturbance regime patterns
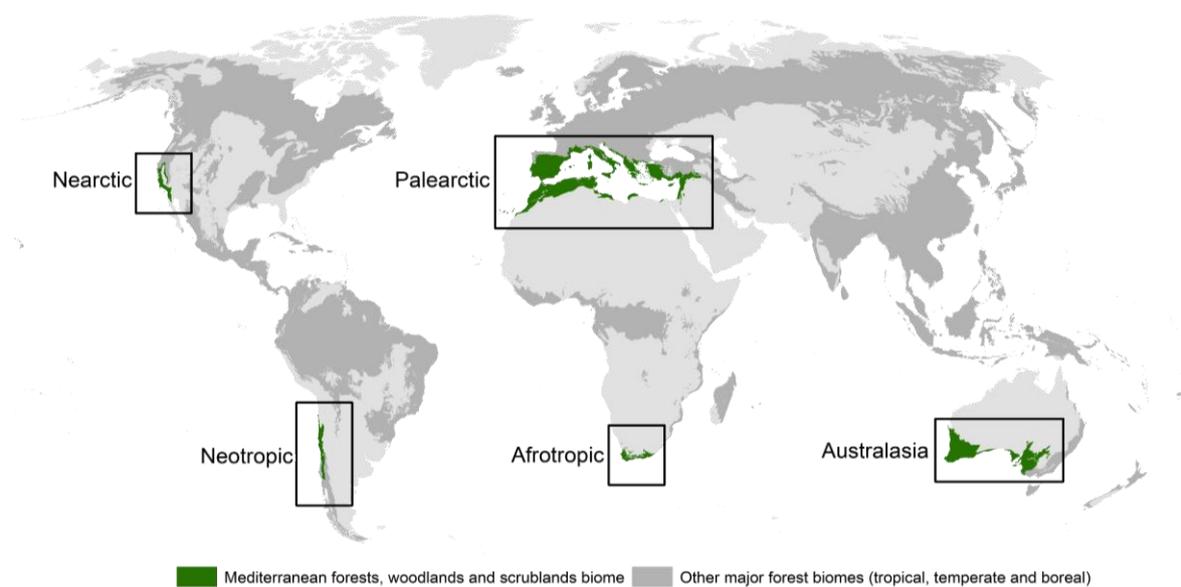
Source: Ecoregions (Dinerstein et al 2017)

Fig. 1: 40 ecoregions constitute the *Mediterranean forests, woodlands and scrublands* biome (Dinerstein et al 2017)

Table 1: Forest and disturbance definitions used

Definition	Criteria	GFC	FAO forests (FRA2020)	FAO forests + other wooded lands (FRA2020)	ESA (2017)
Tree cover masking for year 2000	Tree height	> 5 m	> 5 m	> 5 m	> 5 m
	Canopy density	>10%	>10%	>5%	15%
	Minimum forest patch	>0.09 ha	>0.5 ha	>0.5 ha	9 ha
	Land cover classes	None	Non-agricultural and non-urban classes in 2000	Non-agricultural and non-urban classes in 2000	All classes having a dominant tree cover in 2000
Loss masking for the period 2001-2015	Tree cover	Inside tree cover selected	Inside tree cover selected	Inside tree cover selected	Inside tree cover selected
	Land use change	Agricultural Urban	Agricultural Urban	Agricultural Urban	Agricultural Urban

Results & discussion

Disturbance rotation periods calculated at the ecoregion level and averaged among definitions show that most Palearctic (European and North African) Mediterranean ecoregions tend to have longer rotation periods of around 651 years in average, while Australian and North American ones have the shortest ones, being as frequent as 42 years in the heavily wildfire-disturbed Esperance mallee, Australia and 62 years in California montane chaparral and woodlands (Fig 2). The only notable exception is Hampton mallee and woodlands, along the Southern coast in Australia, which exhibits unrealistically long rotation periods (17,870 years) and is interestingly situated next to Coolgardie woodlands, one of the most extensively burnt ecoregions in the world (Acil et al 2021). This lack of disturbance events, despite a fire-prone vegetation, is because the period examined between 2001 and 2015 corresponds to a recovery phase following a previous wildfire. Around half of this ecoregion burnt 2017 and 2018, as detected in the GFC product.
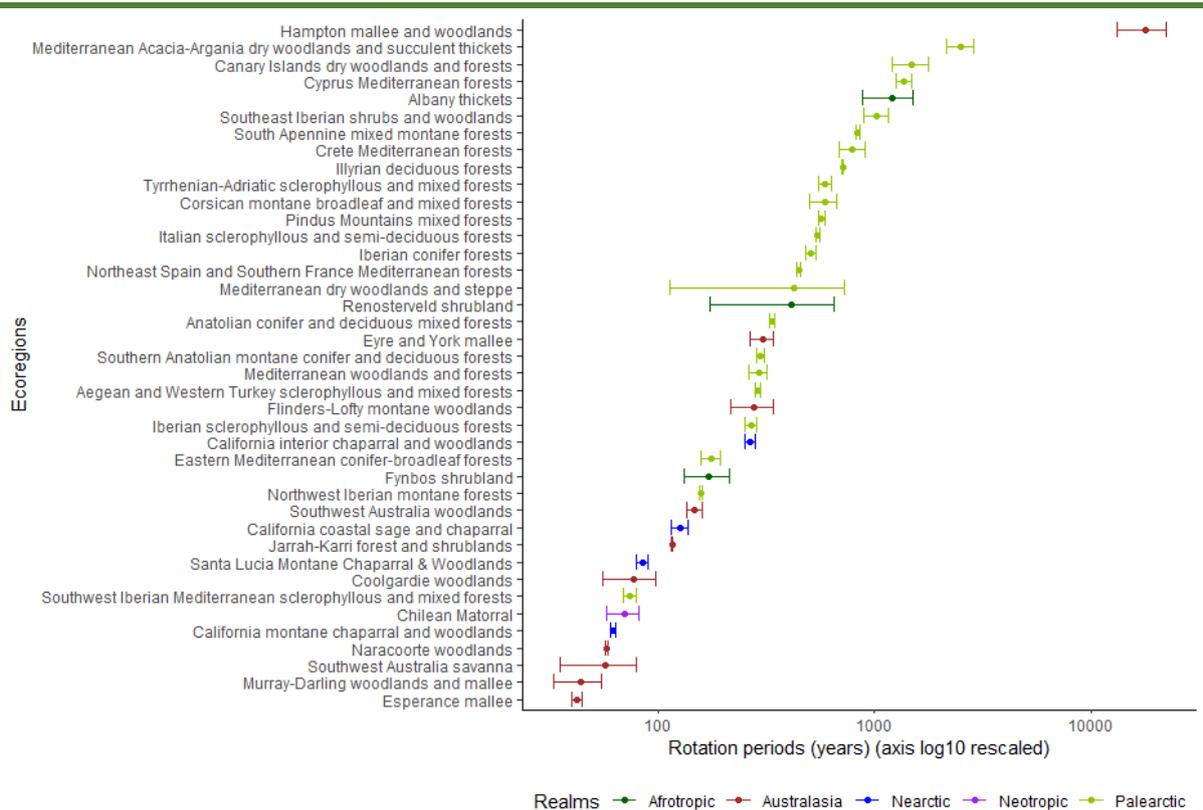
Fig. 2: Mean and error bars (+/- 1 standard deviation) of the disturbance rotation periods (years) per ecoregion calculated with the different forest and disturbance definitions

Standardised uncertainty, expressed as coefficient of variations, indicate that the most sensitive ecoregions are those with extensive dry shrublands, savannas and steppe-like vegetation in Africa and Australia (Fig 3). The highest uncertainties are in fact recorded in Mediterranean dry woodlands and steppe in North Africa (73.28%), Renosterveld shrubland in South Africa (57.98%), and Southwest Australia savanna (38.21%). The least sensitive regions are those moist coastal or mountain forests and shrublands in Australia and Europe, namely Jarrah-Karri forest and shrublands (0.43%), Illyrian deciduous forests (1.08%) and Naracoorte woodlands in Australia (1.17%).
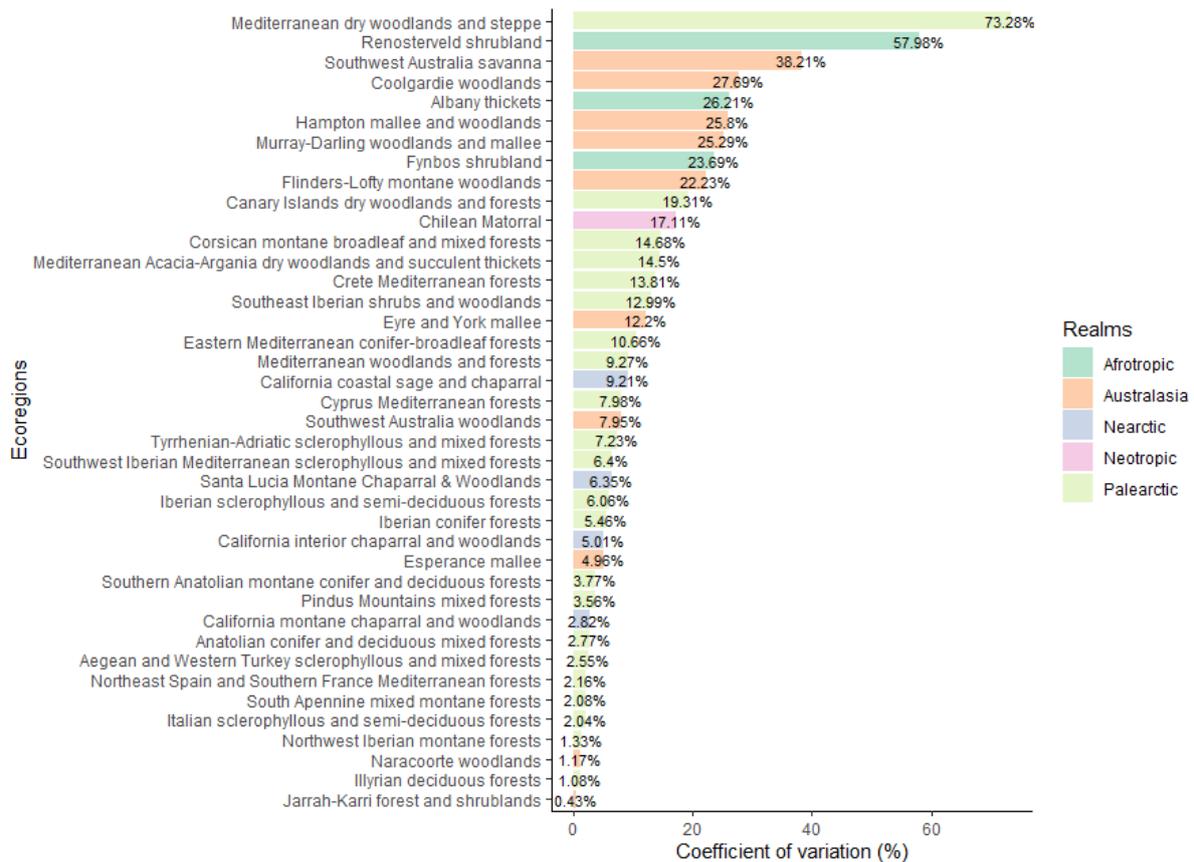
Fig. 3: Uncertainty of rotation periods, expressed as coefficient of variation (%)

At the biome level, the Mediterranean biome exhibits larger uncertainty than the boreal, temperate and tropical moist broadleaf and coniferous forests (Fig. 4). It remains, however, less sensitive to definition changes than tropical and subtropical dry broadleaf forests.
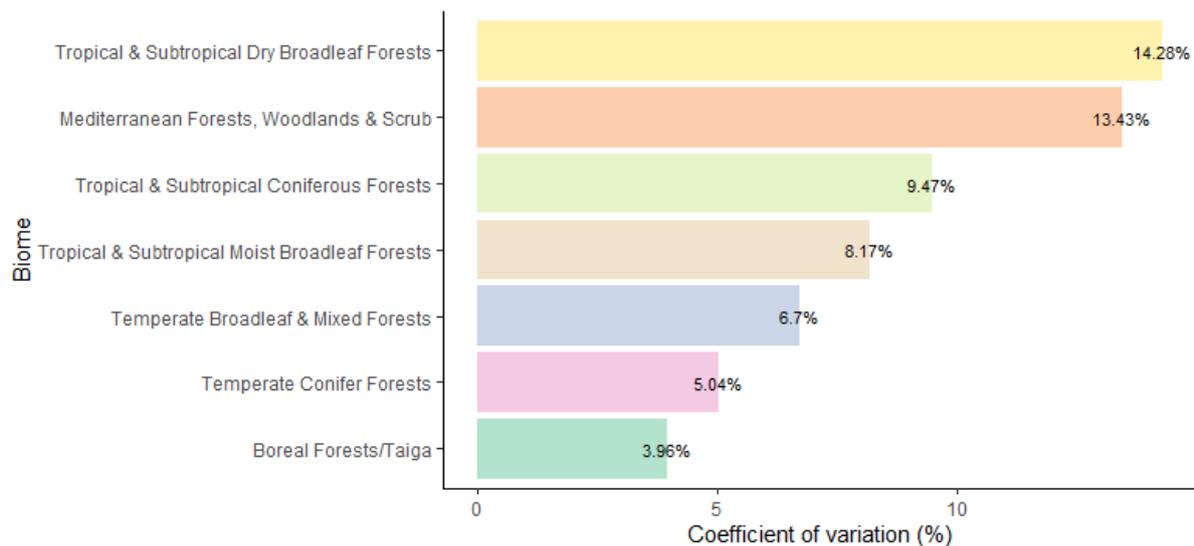

Fig. 4: Comparison of uncertainty in the Mediterranean biome with other major forest biomes (means by ecoregions)

Discussion

We quantify substantial uncertainty in estimates of disturbance rotation periods with the different definitions across Mediterranean ecoregions. For two ecoregions, the uncertainty exceeds 50 % of the variation relative to the mean. The most sensitive ecoregions are those that have wilder areas of bush-savanna-steppe-like formations, as well as those that are subject to recurrent large disturbance events, such as seasonal large bushfire in South Australia. The least sensitive ecoregions are those wetter and more remote forests in coastal and mountainous regions, as well as those that are closely managed.

Although uncertainty in Mediterranean forests exceeded that in boreal and temperate biomes, it was less, on average, than in the tropical and subtropical dry broadleaf forests. This may be linked to the fact that large areas of forests in these tropical dry lands have their continuous cover perforated by small-scale human activities, which are picked up by the 30 m resolution of Landsat, but are not detectable in the more coarsely-resolved ESA landcover dataset. Such activities may include shifting agriculture and selective logging for charcoal production or timber harvesting (Curtis et al 2018, Tyukavina et al 2015, Turubanova et al 2018).

The process of deciding a baseline for forest cover to use in disturbance regime assessments should carefully consider if the criteria and thresholds used are fit for purpose. Using remote sensing-based methods developed to focus only on dense and large continuous cover forests might not give a representative depiction of forest situation in dryland biomes, where forests tend to be highly fragmented or with a low density (Bastin et al 2016). The same goes for excluding remnant forests in human-dominated agricultural or urban landscapes. Developing forest definitions that better delineate such highly dynamic, fragmented, and/or young recovering forests may be needed to reduce uncertainty.

Conclusions

This work constitutes a first step toward comparing and evaluating the suitability of forest definitions for a global assessment of disturbance regimes. Identifying a harmonised method that considers the specificities of different forest types, such as those in the Mediterranean biome, and that are highly fragmented or intermingled with other vegetation formations, is needed to provide consistent quantification and facilitate intercomparison among regions. Such quantification can help improve global projections of climate change impacts and better inform planning and decision making.

Appropriate representation of forests, encompassing those that are undergoing continual structural changes, will help provide a more accurate depiction of disturbance regime characteristics, and thus help managers adjust their strategies and action plans to historically prevailing disturbance regimes, which is needed to maintain the integrity and resilience of forests. Identifying where disturbance regimes are intensifying without excluding those forests will help planners design and adopt appropriate adaptation and mitigation measures. Such information is of crucial importance in the Mediterranean biome, where climate change is driving longer episodes of extreme drought and more frequent large wildfire events (Peñuelas et al 2017).

Identification of definitions targeted towards particular regions and/or purposes (e.g. bushfire management) will require discussions with key stakeholders, ranging from national forest policy makers to global carbon cycle scientists. Results of these discussions could be propagated forward into dedicated disturbance regime products, validated against regional ground observations.

Acknowledgements

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