Doctorate in Environmental and Evolutionary Biology

Title: Climate change and co-occurring disturbance effects on the Mediterranean coastal forest ecosystems undergone to several management and socio-economic conditions.

PhD. Project

Curriculum “Ecological Sciences”

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According to the Intergovernmental Panel on Climate Change (IPCC) report, the global average temperature for the 1880–2012 period has increased by 0.85 C, with a difference of + 0.78 C between periods 1850-1900 and 2003–2012 (IPCC 2013). Furthermore, the carbon dioxide (CO2) concentration has increased by more than 25% in the last century (Smith and Smith 2009). According to the IPCC fifth assessment report on climate change, CO2 concentration has increased by 40% primarily due to two anthropogenic processes: fossil fuel emission and deforestation (land use change) (IPCC 2013). Numerous empirical and modelling studies had clearly shown that extremes climate conditions associated with climate change are on the rise (IPCC 2013). Of all climate extremes, drought is one of the commonest and most costly disasters (World Meteorological Organization 1992). At EU level, drought intensity and frequency are expected to increase with global warming in southwestern parts of Europe, whereas an opposite signal is projected for north-eastern Europe. With climate at 3°C global warming applied to Europe’s economy in 2015, aggregated annual drought losses in Europe would increase with 90% compared to losses in present climate (JRC, 2020).

European countries are increasingly facing floods, heatwaves, prolonged droughts, unpredictable river flows, temperature rises and decreased rainfall with related impacts on vegetation. These phenomena are closely related to human development and climate change. Their impact is expected to exacerbate the actual risks, particularly in regions where water scarcity is already a concern. In the Mediterranean area, the impacts of climate change are becoming increasingly perceptible and severe. Many semi-arid regions are suffering significant declines in water availability and temperature increase, enhancing thus the desertification dynamics and forest fires. Furthermore, the effects of extreme droughts on tree mortality in forest areas are becoming a very serious problem (de la Serrana et al. 2015).

It is important to note that climate change effects on forest ecosystems can be the direct or indirect causes for other stress factors involved into the forest decline throughout weakening ecological systems and making them more susceptible to biotic and abiotic stresses, such as changes in the composition and structure of tree community, up to extreme cases of high and sudden forests mortality (forest dieback). Throughout Europe, these changes have affected many forested areas showing a wide variety of symptoms (crown thinning, discoloration or yellowing of leaves, formation of leaf clusters, dieback of branches, formation of epicormic shoots and bark lesions). The low specificity of these symptoms, together with the many single causal factors (Oosterbaan & Nabuurs, 1991; Brasier, 1996; Siwecki & Ulfnarski, 1998; Thomas & Hartmann, 1998; Gallego et al., 1999; Jung et al., 2000; Lloret et al., 2004; Jönsson, 2006), suggest that forest decline could be attributed to several different site-specific factors, and/or to a synergistic activity of several abiotic and biotic factors (Thomas et al., 2002; Gutschick & BassiriRad, 2003; Bigler, 2006; Levanic, (2011).

AREA STUDIO AND OBJECTIVES

In this project, three coastal forest ecosystems undergoing to various kinds of pressures will be taken into consideration:

- The Palo Laziale site; it is located in the Latium and is characterised by a flat area of about 50 hectares. The area is comprising of an oak floodplain forest with some temporary ponds, high Mediterranean scrubs dominated by *Phillyrea angustifolia*, *P. latifolia* and *Pistacia lentiscus* and a meadow extending for about 18 hectares between the forest and the sea-shore. These plant communities establish the core of the 'Bosco di Palo Laziale' Natura 2000, which is now in a state of serious structural and functional decline.
- The El Bruc site, located in Catalogna - Spain, is 700 ha wide at an elevation of 450-500 m asl and belonging to private properties. In 2015, this area has been completely involved to a natural fire, burning almost entirely. However, El Bruc area showed a high level of soil degradation (soil erosion) and land abandonment formerly in 1986. It is important to note that it represents a protection and connection corridor for the Montserrat-Roques Blanques-riu Llobregat SCI (code ES5110012), an emblematic area with a high touristic, aesthetic, and ecological values.
- The Nestos site, located in east Macedonia - Greek. The Nestos site is the largest remaining riparian forest in the Mediterranean area, protected within the 'Delta Nestou' Natura 2000 site. This is of great ornithological value, but in past decades has been severely reduced in size. Habitats and species in both Natura 2000 sites face several serious threats, including shrub expansion and invasive species encroachment, eutrophication, and inappropriate forest and water management.

The principal aim of this project is to study the structural and functional alterations that climate change and co-occurring disturbance effects have on Mediterranean coastal forest ecosystems by defining and analysing some environmental and socio-economic drivers affecting the ecosystem's health, also taking into consideration their synergistic contributions. This project will be developed through an up-scaling approach, where four levels of biological organization will be interested to the structural and functional analyses:

- Individual
- Population
- Community
- Landscape mosaic

This multilevel approach should allow a systemic vision able to evaluate the climate change effects on the different structural and functional components of a forest ecosystem, adopting scale-depending measuring approaches. In this way, it will be possible to analyse the climate change and co-occurring disturbance effects along all organization levels, and as a consequence, to identify the extent and direction of the environmental risk in order to set up an efficient ecological restoration plan.

Many studies have largely considered the structural and functional alterations on individual species due to the rainfall decreases and temperature increase. Other studies have been carried out by using remote sensing data to evaluate structural changes of a forest area during a given period of time. However, few studies have evaluated the structural and functional alterations by an integrated and systemic analysis. In this project, the Mediterranean coastal test sites will be analysed as a system at different scales, in order to define their functioning and response ability to the environmental drivers and management activities. Therefore, it will be essential to analyse the test areas and collect as much data as possible about structural, pedological, phytosociological, ecological and socio-economic data. In addition, it will be important to realise an inventory of changes occurred in the structure and boundaries of these testing areas during the last twenty years.

The impacts of climate change will concern:

- Adaptation to the risk of desertification: through the study of soil properties and water retention, estimation of the water balance at different scales (from individual to forest) and the water use efficiency;
- Adaptation to the risk of biodiversity loss: through the study and analysis of the habitats, ecological status of the plant species and species-specific biodiversity;
- Evaluation of the effectiveness of the on-going ecological restoration actions and inter-comparisons among the three test sites in order to characterise the Mediterranean coastal ecosystems to counteract future changes of climate.

PHASES OF THE PROJECT.

In the first year of the project, it will be important to conduct a thorough analysis of the existing bibliography in order to collect data for the Mediterranean coastal ecosystems undergone to different management activities and/or climate change-induced degradative processes. Therefore, in the first year, it will be essential to develop a series of environmental (micro- and meso-climate, soil properties, phytosociological surveys) and structural (dendrometry, coverage) databases for each test site to be used for future statistical and numerical analyses. Because the chosen test sites are included in several European founded projects for the restoration of degraded areas, most of these data have already been collected.

The sampling strategy includes:

- To collect climatic data by using existing weather stations inside or near the test areas for at least twenty years. A geo-based climate database will be created by using data provided by the Integrated Agro-Meteorological Service (SIARL) of ARSIAL for Italy, and from the National Meteorological Authority and Laboratory of Meteorology - School of Geology, Aristotle University of Thessaloniki for Greece. As regards the data of Catalonia, the weather stations closest to the area will be used for the setting up of the climate database. These data will provide a precise picture of the local trend of temperature and precipitation over the last decades. It will thus be possible to assess the extent of climate change at the local level and to evaluate its effect on habitats regarding increase of drought due to the rise in temperature and the rainfall decrease. Based on these results, it will be possible to quantify the water availability in these coastal Mediterranean ecosystems, also crossing data with those from forest cover. The collected data will also be useful for the implementation of the Water Management Plan to define the best strategies for the ecosystem's adaptation to climate change.
- Estimation of forest evapotranspiration through direct and indirect methodologies such as the sap - flow measurements at individual level and their upscaling to the forest by using several evapotranspiration models (Turc, Penman-Monteith, process-based models, energy balance models).
- Estimation of water use efficiency (WUE): Evaluate the water use efficiency over time to assess the occurring water stress induced by climatic alterations or wrong management strategies. To evaluate this parameter, it is necessary to measure the carbon assimilation either at leaf level or canopy and forest level. In this case, gas exchange measurements will be carried out at leaf level and will be upscaled at the forest level by using existing model such as the big-leaf approach and multilayer models all based on the process-based gas exchange models (Farquhar and von Caemmerer biochemical model).
- Satellite data (Sentinel 2 or Modis) will be used to estimate primary productivity and evapotranspiration al forest level at aim to compare with the modelled one (top-down approach).

In the second year, satellite images will be analysed, and therefore, forest indices will be quantified such as NDVI, WDRVI, GNDVI, LAI, SAVI, water stress indices (NDMI and NMDI) and chlorophyll indices (TCARI / OSAVI) all calculated by Sentinel 2 data. The satellite acquires images every 5 days at a spatial resolution of 10 meters and the indexes are available for all acquisition dates of the last 365 days. Once these data have been obtained, it will be possible to implement the databases regarding the three test sites and submit them to statistical surveys. Trend analysis concerning satellite-based indices and functional parameters (gas exchange and water use efficiency) will be carried out by using the non-parametric Mann-Kendall trend Z test (Mann, 1945; Kendall, 1975). If Z is lower than the theoretical one at $p<0.05$, then no trend is detected in the time series; If a linear trend is indeed present in a time series, then the true slope (change per unit of time) can be estimated by using a simple non-parametric procedure developed by Sen (1968). The trend analysis should discern about similarities or not among the temporal dynamics of selected predictors. Trend analysis will be carried out by using the R statistical package – *Trend* (version 0.2.0, 2016). Random forest analysis (Breimann, 1996, 2001) – a machine learning method, will be carried out in order to improve the performance of decision tree while retaining most of the appealing properties considered for determining the most important predictors significantly affecting a response variable. With this technique, no precise information is required about the form of the relationship between response and input variables. The final predictor importance values are computed so that the highest average is assigned a value of 1, and the importance of all other predictors is expressed in terms of relative magnitude of the average value of the predictor statistics, relatively to the most important predictor (Svetnik, 2003). In this analysis, the most important predictors will be selected until their percentage difference with the most important one will be 30%. The most important predictors highlighted by Random Forest analysis will be used to define causal relationships with important depending variables (carbon assimilation, evapotranspiration, water use efficiency) and non-linear regression analyses (GRM, GAM, PLS) will be performed to formalise and quantify these relationships. These analyses will be performed by using the statistical package STATISTICA 12 (StatSoft).

In the third year, the ecological restoration techniques implemented for each site will be analysed. The health state of the testing areas will be compared before and during the ecological restoration. We will try to underline the pros and cons of each strategy implemented. Taking into consideration all causal relationships found, it will be possible to outline a detailed picture of the restoration actions, and we will try to define the most favourable approach for each of test sites, at aiming to minimise negative impacts induced by climate change and co-occurring disturbance factors (fires, drought, management). it is, therefore, necessary to create a series of protocols allowing, through the study of the characteristics of each area, to choose which restoration action is actually more suitable for a given Mediterranean coastal site. In fact, the speed with which climate change is occurring is greater than the change in which Mediterranean forests have evolved and, as a consequence, are exposed to an uncertain future, at least for those less adapted to drought conditions.

During the three years of research, the sustainability and feasibility of the actions implemented will be considered. Forest ecosystems are a source of important ecosystem services from various points of view, as well as the three sites considered, not only for an intrinsic value, but also because they are a source of cultural, social and economic well-being for man. Furthermore, the health of these complex ecosystems, that are threatened by climate change, is important to counter the latter thanks to the assimilation of carbon. Therefore, good forest management is essential to stem climate change, and to be able to enjoy the ecosystem services from which we benefit today.