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Title page

Natural and human impact in Mediterranean landscapes: an intriguing puzzle or only a question of time?

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ABSTRACT

Time is a key factor to understand the effects of disturbance on natural communities or ecosystems. In Mediterranean landscapes, where nature and humans have been strongly intermingling since mid-Holocene, the relationships between plant ecology and palaeoecology and their role for the interpretation of natural and anthropogenic changes still needs to be clearly understood. Ecology and palaeoecology are both investigating such problems, but each of them cannot disentangle the specific role played by nature and by humans in shaping the present plant communities and landscapes. A new age of cooperation among researchers in ecology and palaeoecology is needed, and the integration of these closely related but separated research fields is necessary to explain the resulting dynamic puzzle. Plant ecologists should avoid the oversimplification of the actual causes as the exclusive drivers of plant communities and landscapes and force the exploitation of the available data to generate and test new hypotheses for past, present and future environmental reconstructions and management. Even when planning for the future biodiversity conservation, we need to properly use the existing information about millennia of human effects on the natural biotas, to properly set landscape management and conservation priorities.

KEYWORDS: Anthropocene; global change; interdisciplinarity; science oversimplification

INTRODUCTION

Biotic responses to disturbance are time and space dependent (Vegas-Vilarrúbia *et al.*, 2011) and the effects of natural and human disturbance on natural communities or ecosystems may appear after long time (see e.g., Rajendra *et al.* , 2014). Thus, time is a key factor to understand the effects of disturbance on natural communities or ecosystems (Essl *et al.* , 2015). An interaction between two closely related disciplines, *palaeo*ecology and ecology (*neo*ecology or contemporary ecology), can facilitate this understanding (Vegas-Vilarrúbia *et al.* , 2011; Guerin *et al.* , 2014; Seddon *et al.* , 2014; Reitalu *et al.* 2014) and provides mutual benefits: palaeoecology is essential to understand long-term changes, while ecology provides functional bases to properly interpret the changes observable in palaeo-records (Birks *et al.*, 2010; Mercuri *et al.*, 2013).

Recently, an increasing amount of papers described the positive collaborations among palaeo- and neoecologists, especially in Northern Europe (e.g. Marquer *et al.*, 2014; Reitalu et al., 2014). However, we argue that this issue still needs to be addressed, studied and clearly understood in the Mediterranean area where this type of cooperation is almost lacking. The Mediterranean area experiences an extraordinary long history of human societies, that developed an increasing capacity of transforming vegetation and landscapes, interlacing their action with the natural disturbance factors (Butzer, 2005; Mercuri *et al*., 2015a; Izdebski *et al.*, 2016; Sadori *et al.*, 2016a; 2016c). In this area, where nature and humans have been intermingling since at least the early- mid-Holocene, the reciprocal effects of the human vs natural drivers of landscape modification has been invoked several times, but rarely analysed and plainly interpreted.

In this framework, the adoption of a long-term approach to explain the relative role of both natural and human disturbances, could permit to disentangle their strict interactions in determining past and present responses of plant communities and landscapes. Are ecologists taking into the right consideration the information coming from palaeoecologists (and *vice versa*)? We discussed our ideas using recent literature and a pollen record for the last 7000 years from the central Adriatic sea.

PALAEOECOLOGY AND ECOLOGY: JUST A MATTER OF SCALE?

Despite disturbance and time scales are concepts strongly related, research approaches divide palaeoecology and ecology into almost separate disciplines (Froyd and Willis, 2008 but see Gillson and Marchant, 2014; Mercuri, 2014; Bjune *et al.*, 2015). Palaeoecological and ecological investigations are rarely planned on the same site: this is due to different specialisations, relevant differences in data source, methodologies and a lack of stable cooperation (Reitalu *et al.*, 2014). Sometimes, palaeoecologists and ecologists use a similar terminology to indicate different concepts, while other times the same concept is described with different terms. Hence, we need to invest time and resources in finding the way to share expertises and even the language (Seddon *et al.*, 2014).

For example, in palaeoecology an “indicator species” corresponds to a species with known ecological needs and used to infer specific features of the past plant cover (Birks *et al.*, 2010), while in ecology this concept indicates the fidelity of a certain species, or group of species, to a certain plant assemblage (e.g., Chytrý *et al.*, 2002). The two concepts are somehow related, but differ significantly. Palaeoecology describes processes at much coarser spatial and temporal scale and the use of indicator species permits to depict the underlying processes (e.g. when palaeoecologists infer trampling from the presence of *Plantago*). In ecology, a similar concept is adopted at meso-scale and macro-scale (e.g. when ecologists refer to the present climate needs of *Quercus ilex*), but the use of such concept is less reliable in heterogeneous landscapes, where the important gradients in species composition appear at fine spatial scales (Heikkinen *et al.*, 1998).

Present plant communities composition is influenced by both present factors (e.g. species-sorting, biotic interactions, adaptation and ecological drift) and by pre-existing drivers (Essl *et al.*, 2015; Guerin *et al.*, 2014): the species pool of a region is a product of long term processes affecting that region, but it influences the existent plant communities (Pärtel *et al.*, 1996*)*.

When interpreting disturbance, time and space are common issue for palaeoecology and ecology, but often with different grain and extent (Froyd & Willis, 2008; Bjune *et al.*, 2015).

HUMAN IMPACT ON MEDITERRANEAN ECOSYSTEMS – AN INTRIGUING PUZZLE

A growing attention is dedicated to human impact and to the concept of Anthropocene (e.g. Lewis and Maslin, 2015 *vs* Hamilton, 2015). Human impact on vegetation includes the direct and indirect effects of ecosystem transformations: it is a collective concept assembling adaptive strategies, technological outputs and interferences with natural ecosystem dynamics (Mercuri *et al.*, 2015a). Whatever the impact, its effects can be traced studying vegetation and fire history (Sadori *et al.*, 2013, 2015, 2016a). In the last millennia the impact of humans on ecosystems progressively increased, depending on technological advances and demographic growth (Mercuri, 2014).

In the Mediterranean, humans greatly influenced the actual patterns of landscape complexity (Mazzoleni *et al.*, 2004). Each culture was built on a previous culture and, therefore, each new land-use started from an old land-use, in an already human-shaped landscape. Correspondingly, the present distribution of many species of cultural interest, e.g. *Olea*, *Juglans* and *Castanea,* is largely the result of long-term history of land-use changes and human management, rather than an output of climatic, biotic or ecological changes (Mercuri *et al.*, 2013).

Past trades and social changes affect present vegetation because of the voluntary spreading or introduction of useful and new species (Bosi *et al.*, 2009, 2015; Sadori *et al.*, 2016a). The human driven spread of plant species for cultural purposes (sacred, food, fire, building) is one of the most peculiar features of the Mediterranean area, where these processes are documented at least since the Bronze age (e.g., Mercuri *et al.*, 2015b; Rosati *et al.*, 2015).

In absence of palaeoecological and ethnographical data, the present landscape configuration can be erroneously associated to a recent phenomenon, ignoring the human impact that probably had major long-term consequences. For example, in a recent study Frascaroli et al (2016) demonstrated that, in central Italy, sites with presence of historical shrines host a higher plant diversity and large trees, demonstrating a major role of long term drivers on present plant communities and landscapes. On the other hand, the shift from a nomad pastoralism to sedentism life style caused local overexploitation in some arid habitats and the over-grazing caused a progressive desertification, forcing people to migrate in new lands (e.g. Garcea *et al.*, 2013).

The resilience of the investigated systems and their responses may occur at single species or landscape level, mixing up the understanding of phenomena occurring at different time scales. Population models approach demonstrated species' fluctuations in long temporal lags, useful to stress the importance of the long-term population dynamics approach to evaluate the vulnerability of modern fragmented plant populations (e.g. Di Domenico *et al.*, 2012), while at landscape scale the role of fire in prehistorical and historical societies is still debated (Vannière *et al.*, 2008; Sadori *et al.*, 2015).

Integrating data along the time scale

In Mediterranean and north-African regions the early Holocene was characterised by wet and cool climate conditions and characterized the early Epipalaeolithic/Mesolithic transition (Cortés Sánchez *et al.*, 2012). Then, the climate became progressively more arid, with oscillations in temperature and precipitation and increasing seasonality, especially after 6000 years before present (hereafter BP, Mercuri and Sadori, 2014; Peyron *et al.*, 2013).

Vegetational changes observed in the past, are often referred to climatic drivers, but this is not always the case. The trend of tree abundance changes in pollen diagrams is classically considered a good indicator of climate change, but it can respond to different forces. For palynologists the interpretation, for records of Pleistocene age, is straightforward: high amount of arboreal pollen (AP) indicates forest and interglacial conditions and low amount of AP stands for steppe/grasslands typical of glacial periods (Sadori *et al.*, 2016b; 2016c; Tzedakis, 2005). Due to the high sensitivity of plants to changes in wetness/water availability, decreases in humidity can cause sudden and strong forest openings. When dealing with the Anthropocene, we have to be aware that forest clearance can respond also to other forces as human impact. Both climate and humans can in fact cause a vegetation shift from forest to grassland communities.

In central Italy (Vannière *et al.*, 2008), a decline of evergreen oaks occurs when the frequency of fires increased at the Mesolithic/Neolithic transition. In southern Italy, instead, a biomass drop and an increase of olive pollen are evident from the Neolithic onwards (Sadori & Narcisi, 2001; Mercuri *et al.*, 2013), but its interpretation is still under debate (Mercuri, 2014; Mercuri & Sadori, 2014; Zanchetta et al., 2013). It becomes evident that the complex systems we observe in presence of humans, which represent the vast majority of vegetation units and ecosystems, can only be understood by studying the interactions between the natural drivers and those induced by human direct and indirect activities throughout millennia.

After considering the synergic effects of climate and anthropic forces on vegetation, the question is: was the response of vegetation synchronous with the climatic and human drivers?

Were xerophytes favoured by the aridification of climate or were forests damaged by humans?

To exemplify the strictly interlaced dynamics that link human impact to climate change, we show pollen data from a marine record of the last 7000 years (RF93-30) drilled offshore of Apulia region (Central Adriatic, Italy). It exemplifies the landscape changes occurred at macro-scale as, for the water circulation of Adriatic Sea, it is mainly gathering pollen transported into the sea by the main river of Northern Italy, the Po river (see Mercuri *et al.*, 2012; Fig. 1).

At around 5300 years BP a forest clearance due to decreasing *Abies, Fagus*, *Picea* and *Taxus* matches a trend similar to that observed in terrestrial cores of Northern Italy.

We can interpret this opening of the forest as general increasing aridity conditions resulting in the development of drought-resistant vegetation. The other side of the coin is that such trend in the abundance of tree species can also be explained by the increasing human activity in the Po plain at the beginning of Copper age. This is evident by both archaeological records and the presence of anthropogenic pollen indicators in diagrams (e.g. cereals, Cichorieae and other synanthropic species). Open landscapes and xerophytes spreading became more and more common. Soon after 3900 years BP a rise of cereals and synanthropic weeds coincides with a heavy agricultural use of land during the Bronze age in Northern and Central Italy. The marine core clearly records the strong landscape change occurring inland when the impact of human populations become widespread in the region. Most anthropogenic pollen indicators (API, Fig. 1) rise after 3600 years BP, when the Middle Bronze age culture in the Po valley was shaping a wide landscape (Mercuri *et al.*, 2015a; 2015b). Forest clearance mainly interested deciduous *Quercus* while, as collateral effect, Cichorieae and Poaceae curves reflect the expansion of open vegetation caused from ongoing human impact (Florenzano *et al.*, 2015). The increase of OJC (*Olea*, *Juglans* and *Castanea* group), representing the joint rise of 'cultural trees' shows a first expansion at 3300 years BP and an unquestionable further expansion at around 2100 years BP, during the Roman period. This might represent the effects of human selection under favourable climatic conditions. Around 900 years BP a decrease of deciduous *Quercus* could be either ascribed to agriculture and demographic increase or to climate change. A doubt is also advanced for the following recover of mixed oak wood: was it due to climate change or to reduced human impact?

Even if thousands of archaeological sites and archaeobotanical research demonstrate that it is hard to find areas with negligible human presence in Italy (Mercuri *et al.*, 2015c), local evidence often shows that ecosystem dynamics could have been primarily driven by climate (Sadori *et al.,* 2004, 2013, 2016a). Independent climate proxies and instrumental data indicate that the last millennium was a period of important climatic changes: first a warm and relatively dry period (Medieval Climate Anomaly, MCA, ca. 1000-800 BP), then a wet and cool period (Little Ice Age, LIA, ca. 600-150 BP) occurred (Sadori *et al.*, 2016a).

CONCLUSIONS

What can we learn from the past? Human adaptation has been triggered by difficulties, in more or less rapidly patterns depending on the cultural framework and environmental characteristics (Cremaschi *et al.*, 2016; Essl *et al.*, 2015; Sadori *et al.*, 2016a).

Various studies dealing with natural *vs* human drivers of change in vegetation underline the difficulty in disentangling the main agent of transformation of Mediterranean habitats and landscapes in the last millennia (e.g. Roberts *et al.*, 2011). In addition, other evidences interfere with a clear interpretation of data: cereals (Cerealia type) include also pollen of other Poaceae native of the Mediterranean area; most of the anthropogenic pollen indicators are also general indicators of arid environments and a number of weed and ruderal taxa are common and abundant in pre-Holocene times, widespread during Late Glacial dry oscillations and partly during the early Holocene (Mercuri *et al.*, 2012, 2013). Therefore, the debate on the issue if xerophytes were favoured by the instability of climate or if forests were just cleared by humans – on a long-term perspective - is still on (Prentice *et al.*, 2000 *vs* Collins *et al.*, 2012).

Nevertheless, the Adriatic core exemplifies an archive of vegetation changes for the last millennia: reading the chronological transect it appears clear that the decrease of deciduous *Quercus* forests follows a pattern where hilly and lowland vegetation belts have been used (and abused) since the Copper age; this pattern is still visible at Italian (Rosati *et al.*, 2008) and European scale (Ceaușu *et al.*, 2015). Then, is it all human induced? Pollen diagrams, where curves of xerophytes and anthropogenic plants show synchronous signals with increasing trend along the Holocene time-scale, suggest that humans were not the only agent. However, humans reinforced the climate signal.

A different fate was reserved to the remoter *Fagus* forests, that were cut and used but quickly recovered since the pressure was not a continuous, but more a pulsing one.

Even nowadays *Fagus* vegetation is the most protected vegetation type in Italy, following the "high and far" model for protected areas (Joppa *et al.* 2009), as well as the long lasting protection of beech mountain forest established for erosion protection.

We learn from the recent past vegetation history, however, that mesophilous forests with dominant deciduous oaks have been deeply damaged in the last millennia. This was due to the fact that oak woods were both diffused in the most suitable areas for human settlements and agriculture, and they were excellent woods to be exploited for food, fuel and building.

Observation and multi-temporal scale studies cannot untangle the anthropogenic versus natural issue, but the collaboration among specialists can provide more consistent descriptions of past environments helpful to understand and guide the management of present ecosystems.

In scientific research, education is moving toward a progressive great specialization, creating an inevitable condition that penalizes cross-cutting knowledge. The degree of self-reference is high and there is a real risk of proposing and re-proposing the same conclusions just because of the inability to communicate with each other's research results (see e.g. the history of multiple discoveries of sample-based rarefaction in different fields of biology and palaeontology; Chiarucci *et al.*, 2008). After years of hyper-specialization, knowledge and respect of complexity is a hard job for the future research. Dealing with biological matter, and sitting on the 'green' background represented by plants, actuo- and palaeo-ecologists started a difficult but fruitful dialogue. The lack of expertise on a specific issue often leads to its simplification: the cooperation among researchers is the modern must to avoid oversimplification and, on the contrary, allow new exploitation of the available data to provide specialists with more and more chance to formulate and test new hypotheses for past, present and future environmental reconstructions.

When planning for the future biodiversity conservation in the Mediterranean, we are reading a trace left by at least 4000 years of manipulation and changes due to the mixed human/climate impact and we should use this information to properly plan our landscapes and set conservation priorities.

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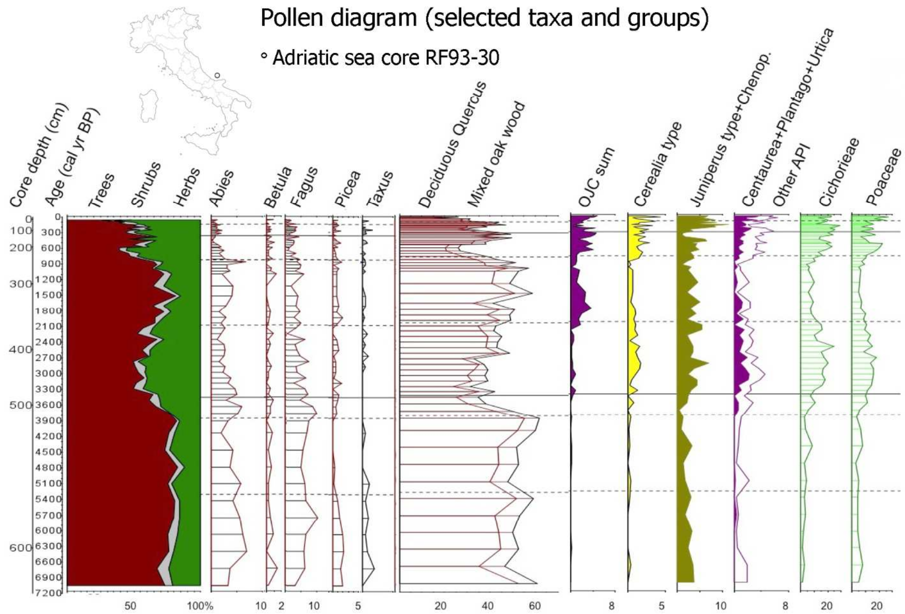
FIGURE CAPTION

Figure 1. Selected pollen percentage curves from the marine core RF93-30 (Adriatic Sea, North of Apulia). Percentage curves are plotted along the age scale (last ca. 7000 cal. years BP, modified from Mercuri *et al.* , 2012). Anthropogenic pollen indicators (API): OJC (*Olea*, *Juglans*, *Castanea*), Cerealia type, *Centaurea*+*Plantago*+*Urtica* (*Centaurea nigra* type, *C. cyanus*, *Plantago lanceolata* type, *P. media/major*, *P.* undiff., *Urtica dioica* type), other API (*Artemisia*, cf. *Cannabis*, *Convolvulus*, *Mercurialis*, *Papaver rhoeas* type, *Polygonum aviculare* type and *Rumex*).



Selected pollen percentage curves from the marine core RF93-30 (Adriatic Sea, North of Apulia). Percentage curves are plotted along the age scale (last ca. 7000 cal. years BP, modified from Mercuri et al. , 2012). Anthropogenic pollen indicators (API): OJC (Olea, Juglans, Castanea), Cerealia type, Centaurea+Plantago+Urtica (Centaurea nigra type, C. cyanus, Plantago lanceolata type, P. media/major, P. undiff., Urtica dioica type), other API (Artemisia, cf. Cannabis, Convolvulus, Mercurialis, Papaver rhoeas type, Polygonum aviculare type and Rumex).

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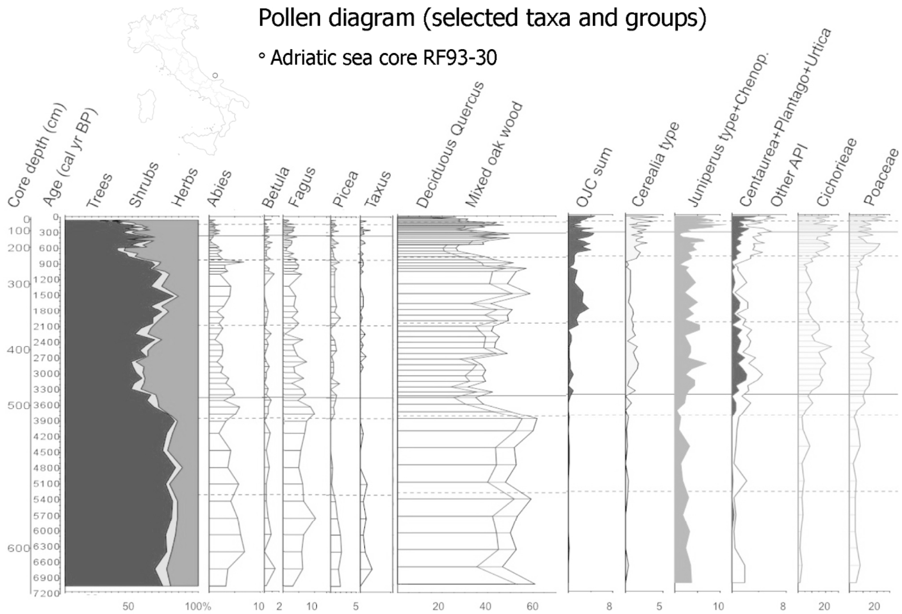

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