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Exotic Plant Species in the Mediterranean Biome: A Reflection of Cultural and Historical Relationships

Irene Martín-Forés

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Abstract

The Mediterranean basin was the world's cradle of agriculture and the first human civilisation. In the Neolithic age, the agrarian culture expanded throughout the Mediterranean basin from the East to the West. Later, an expansion of agrarian culture and trade occurred, associated with the European colonialism, giving rise to a great plant exchange among Mediterranean-type regions. Despite being a biodiversity hotspot, the Mediterranean biome has been subjected to several anthropic impacts, such as alteration of land-use and cross-introductions of exotic species. The millenary anthropic modification of the landscape occurred in the Mediterranean basin gave rise to the formation of seminatural systems in which plants co-evolved with anthropogenic activities over a long time. Thus, species that originated in the Mediterranean basin might have developed a key role in other agro-silvo-pastoral systems along the whole Mediterranean biome. Research is biased towards highlighting the negative impact of exotic species on the ecosystems. To defy the traditional belief, outstanding recent literature focused on the positive effects of exotics on native communities was reviewed. Exotic species seem to have a key role in Mediterranean-type seminatural systems, as evidences of tolerance and facilitation processes were found. Exotic species that have co-evolved with human practices over millennia seem to enhance biodiversity in the Mediterranean biome.

Keywords: biodiversity, coexistence, exotic species, facilitation, grasslands, Mediterranean biome, native species, naturalisation

1. Introduction

Human history and activity have given rise to a wide range of new planetary-scale forces [1] that exert an increasing impact on the ecosphere creating cascades of repercussions on natural and socioeconomic systems [2]. The magnitude of that anthropic influence has increased so much

that a new geological era has been recently recognised, the Anthropocene [3]. The impact and ecosystem alteration exerted by humans on the Earth is known as global change and is of major concern within an ecological framework. Basically, it is a question of an unbalanced growth of human population in relation to the energy consumption by different societies [4] and the fact that human activities occurred at local or regional scale affect the global functioning of the planet [5]. Global change comprehends, among others, changes in carbon cycle [6], climate [7, 8], land-use [9], and areas of species distributions [10]. The areas of species distribution in the context of the Mediterranean biome will be the main focus of the current study. Thus, to fully understand this ecological issue, it is necessary to adopt a holistic approach including the socio-cultural and historical contexts which will allow perceiving the interconnection of all components involved [11].

The Mediterranean basin was, around 10,000 years ago, the world's cradle of agriculture and first human civilisations. During the Neolithic era, the first forms of agriculture and human settlements came up in the territory known as fertile crescent, located in the Eastern Mediterranean, and comprised within the ancient territories of Mesopotamia and Near East. Back to that time, eight founder crops, including four cereals (wheat, einkorn, emmer wheat, and barley) and four pulses (lentil, pea, bitter vetch, and chickpea), were domesticated [12]; moreover, farming activities also started taking place with the associated domestication of several livestock species, including mainly sheep, goats, cattle, and pigs [13]. As a consequence of the human displacements which occurred in Southern Europe from the East to the West, archeophytes (i.e. the exotic species that were introduced before 1500) were established in Western European territories such as the Iberian peninsula. It took about three millennia until the agrarian and farming cultures expanded throughout the whole Mediterranean basin, reaching the Iberian peninsula (**Figure 1**) [14, 15]. Once agriculture and farming were integrated in humans' lives, food supply was under control and populations grew drastically, involving an increase in the dependence on and the intensification of agriculture [16].

Later on, changes in the area of species distribution have occurred in three other key phases. The first key phase took place at end of the Middle Ages (1500 AD), with the European rediscovery and exploration of the Americas [17]. The birth of colonialism at the end of the fifteenth century had consequences in human demography, agriculture expansion, and trade and industrial intensification. The expansion of the European colonial powers (remarkably Spain) radically increased the transport of living material. One major aim associated with colonialism was to exploit new economic crops for the empires. Particularly, the discovery of the New World by Spaniards coming from the Mediterranean basin gave rise to a great surge of plant exchange ([18] and references therein) among different Mediterranean-type regions. This phenomenon was specially marked when first female settlers established in the colonised lands [19]. The second key phase took place during the Industrial Revolution (1800 AD) [20], when traditional forms of rural economy were substituted by urban industrialised and mechanised economy. The third key phase has occurred over the last three decades, related to the rise in ease and efficiency of long-distance transport, income growth [21], and tourism [22], which prompt the globalisation era [20]. As a result, species movement and worldwide interconnectedness have become more intensive, occurring across wider space and in a shorter time than before [23]. Thus, humans' activities have radically modified species' distance dispersal and areas of distribution [18, 24–27].

Figure 1. An integrated model of the Neolithic expansion in the Mediterranean basin. The location and approximate dates of colonist farming enclaves are shown by numbers (calibrated years before present). The darkest areas represent the place settled by colonist farmers; the lightest area indicates where indigenous foragers adopted elements of the Neolithic package and the areas with intermediate tonality indicate areas of the proposed integration of colonist farmers with indigenous foraging groups (modified from Ref. [13]).

As a result of the human-favoured transit of organisms [28–31] and habitat alteration, a reshuffling of species on the Earth has taken place. This gives rise to economic and ecological damage [10, 32–37] and a loss of cultural diversity. In this way, the subsequent biological invasions and biodiversity loss have important consequences at a variety of levels, affecting ecosystem structure [32], function, services, and human wellbeing [38–43], being therefore considered of major environmental and social concern and hence a focus of ecological research [44–47].

In the case of plants, species that have been transported from one region to another are defined as weeds, non-native, exotic, or alien to that new occupied region [48]. The introduction of plant species in an exotic area took place as a result of the movement of specimens around the world with ornamental, gardening, agricultural, and forestry purposes [18]. Since agricultural practices were introduced in human cultures, whenever people moved, plants also did, either deliberately (domesticated crops) or accidentally (associated spread of weeds and ruderal species) [18]. Due to their fast way of reproduction, their ability to withstand difficult environmental conditions through dormancy period in seed form, and the variety of ways of seed dispersal, exotic plants have been traditionally considered as a threat in the biological invasion context, with a greater number of invasive species than animals [32].

Notwithstanding the factors enabling establishment, one of the consequences associated with the colonisation process that has been highlighted in previous reports is that exotic species naturalisation involves landscape and global floristic (taxonomic and phylogenetic) homogenisation of regional flora at a biogeographical scale [49, 50]. Moreover, naturalisation of exotic plants has commonly been considered as a threat to native biodiversity, and most

scientific studies have been centred around their negative impacts instead of considering the socio-ecological opportunities that the introduction of a new species could bring. During the last decades, numerous studies have highlighted the importance of control, monitoring, and managing of exotic species introduced in new areas [51–55]. In fact, many conservation policies have been implemented to conserve the native flora and sometimes, although being controversial, eradicate exotic invaders [56]. As an example, the Strategic Plan for Biodiversity called for urgent action by the parties to the Convention on Biological Diversity (CBD) to reduce the rate of biodiversity loss by 2020 [57]. To that end, they encountered the target of identifying, prioritising, and managing invasion pathways by 2020 to prevent the introduction of invasive exotic species [58]. Despite all this, it has been shown that human influence on the landscape is not always negative regarding the preservation of biodiversity assets. Traditional rural activities also represent important natural values and they maintain a positive relationship with diversity, at least in the Mediterranean biome [59].

2. The Mediterranean biome: historical relationships among the Mediterranean regions

The Mediterranean biome is defined because of its distinctive Mediterranean climate. It is mainly characterised by mild wet winters and warm to hot, dry summers and may occur on the west side of continents between about 30 and 40° latitude [60]. The summer drought period characteristic of the Mediterranean climate has become accentuated by the deforestation that has taken place around the Mediterranean regions during the last 2000 years and the subsequent loss of plant evapotranspiration and evaporation from soils [61–63].

Mediterranean regions with the above-described climatic characteristics are located in five different continents of the planet, including the Mediterranean basin, California, central Chile, Southern Australia, and South Africa. The international relationships and trade activities among these five Mediterranean regions started long time ago, during the colonialism. As an example, the Malaespina expedition (1789–1794) carried out by Spaniards involved four of the five Mediterranean regions; it departed from Spain and reached Chile, California, and Australia.

Although sharing climatic patterns, the five Mediterranean regions have had different biogeographical and environmental histories associated with the density of human populations as well as the time and intensity of the changes and land-use shifts that humans have caused in the territory. Despite being the Mediterranean biome known for its diverse flora, including five of the biodiversity hotspots [56] comparable to tropical rainforests or coral reefs, it has been subject to several impacts caused by humans but with different intensities and durations in each of the Mediterranean regions.

The use of fire and grazing and agricultural practises have been ancestral activities in the Mediterranean basin that play an essential role in shaping the current cultural landscape. The landscape, however, is also subjected to natural phenomena. Among anthropic impacts of important concern in the Mediterranean biome are alteration of land use, habitat fragmentation caused

mainly by land clearing and urbanisation, climate change, alteration of fire regimes, and cross-introductions of alien species [64]. The cultural component generated a landscape maintained and cared for humans by means of reciprocal interactions and interdependencies involving natural processes and human activities. Thus, human culture and technology became integral parts of the ecosystems that underlie the Mediterranean cultural landscapes. In this sense, historical and societal characteristics of the Mediterranean basin, especially those associated with demographic pressure and millenary exploitation of land for agriculture and grazing, determined the patterns of land use change that the territory has presented since ancient times. Those anthropic effects on the environment led to the formation of seminatural systems or cultural landscapes [65, 66]. In fact, agro-silvo-pastoral systems (savanna-like formations characterised by a continuous herbaceous layer with scattered trees and land-use management defined by continuous extensive grazing with a low stocking rate in flatlands and rotation of grazing and cereal cropping in the better-drained hillsides) constitute a characteristic type of exploitation in the Mediterranean biome (e.g. *dehesas* in Spain, *montados* in Portugal). In these socio-ecological systems, plants have co-evolved with people over a long time [67, 68].

Similar cultural landscapes can also be observed in the other four Mediterranean regions worldwide, but the co-evolution of plants with humans has recently occurred, given that effective colonisation times vary depending on the region considered. Due to the fact that Mediterranean regions are enough far away from each other, which impedes the natural flow of exotic species among them, exotic species spreading is expected to follow the cultural landscapes associated with the main navigation routes from the colonialism period onwards (**Figure 2**).

Figure 2. A map of the world showing the five Mediterranean regions and the navigation routes among them. Distances between the regions are shown in nautical miles (modified from Ref. [69]).

For example, Spaniard colonialism occurred in Chile during the sixteenth century due to the expedition led by Pedro de Valdivia that took place in 1541. In central Chile, sclerophyllous forests were cleared and displaced by modified woodlands dominated by introduced exotic species [70], and later those woodlands were opened for grazing and cropping, resulting into grasslands (i.e. called *espinales* in Chile) mostly dominated by species coming from the Mediterranean basin. The implementation of European livestock and agricultural culture led to big direct (ploughing, cropping, and grazing) and indirect (fire and deforestation employed as techniques for preparing the land for agriculture and livestock farming) changes, the extent of which are not well known yet [71]. Associated with the Spaniards arrival, the exotic species were introduced by exozoochory, coupled with merino sheep transported for wool trade, with hay for livestock fodder and with wool and cereals [72]. Several studies have associated the naturalisation (i.e. exotic plants that have been able to establish and self-perpetuate in a new area, according to the definition provided by Richardson et al. [48]) of those plants with processes of grazing by livestock [73–76]. Thus, although Chilean and Spanish plant communities have undergone different processes of invasion, previous reports highlighted the large number of species common to both regions (64% of Chile's non-native flora, [77]).

California was first sighted by Spaniards led by Juan Rodriguez Cabrillo in 1542, after several failed attempts to find a land that was famous for its gold and gems [78]. In the eighteenth century, the Spaniards supported the establishment of ranches granted free of charge, which covered large areas but did not have many inhabitants. The main aim was to support the agricultural and livestock development of the area. Again, the agrarian European culture was exported and implemented in this settlement. The *chaparral* and coastal grasslands of California constitute one of the principal plant formations in the region; they are characterised by having grazing activities and fire as the main agents of disturbance.

South Africa was first sighted by Europeans during the Portuguese expedition led by Bartolomé Díaz in 1488. After that, in the seventeenth century, disputes between Portuguese and Dutch settlers took place and South Africa became a Dutch colony. Finally, in the eighteenth century, South Africa became a British colony [79]. The Mediterranean-type ecosystem of Western South Africa is commonly known as *fynbos*. South African *fynbos* comprise mainly shrublands, grassy shrublands, and grasslands. As in other livestock-based economies, in the Mediterranean region of South Africa, a process of clearing for pasture and grazing intensification also took place [60]. Since then, Europe, particularly the Mediterranean basin, has been the source of 60% of the naturalised exotic grasses in southern Africa [80].

Regarding the Mediterranean region of Australia, Dutch expeditions along the Indic Ocean over the seventeenth century reached the Western Australia State. Nevertheless, British settlers were the ones that finally conquered both Mediterranean regions in Australia. Western Australia was colonised in 1829 and the South Australia State in 1836 [81]. Originally, *mallee* and *kwongan* were typical formations of shrublands and woodlands in this ecoregion. In the late 1800s, large-scale clearing of those formations began giving rise to opened woodlands and grasslands for agrarian and farming activities [82]. Although constituting a biodiversity hotspot, the Mediterranean region of Australia is dominated by naturalised annuals originating from the Mediterranean basin.

For all the above exposed, relationships among all the Mediterranean regions—but of particular importance relationships between the Mediterranean basin and each of the others Mediterranean regions worldwide—have been frequent over the last centuries. As a consequence, natural and ancestral cultural factors based on silvo-pastoral activity converge in the Mediterranean biome, involving the establishment of disturbance regimes that favoured the entry of alien species [73, 83]. Due to the historical-cultural context of the colonialism [19], Europe, and especially the Mediterranean basin, has constituted the main source area donor of exotic flora to the whole Mediterranean biome. Surprisingly, while in some Mediterranean-type ecosystems a displacement of the native flora caused by exotic invaders has occurred, this trend has barely been observed in others. Thus, Mediterranean-type ecosystems worldwide provide a great chance to compare the impact of plant species introduction [84, 85].

3. Exotic plant species naturalisation in the Mediterranean biome

As a result of the landscape transformation carried out by humans in all the Mediterranean regions, empty niches were created (notice that the notion of empty niche does not imply species extinction). That has constituted an opportunity window [86, 87] for the entry of exotic species [73, 83, 88] which were already adapted to disturbances and cultural landscapes [89, 90] in their region of origin for millennia (eco-evolutionary experience [91]). The long-term coexistence of Mediterranean agro-silvo-pastoral systems with anthropic management in the Mediterranean basin has determined processes of co-evolution between plants (crops, forages, etc.) and human practices [67, 76, 92, 93]. In fact, most of the species present in the Mediterranean biome originated in the Mediterranean basin. Plants from the Mediterranean basin presenting more advantageous traits in a context of livestock grazing and ploughing became selected [94]. In particular, among the exotic flora in the Mediterranean biome, the families most represented are Poaceae, Asteraceae, and Fabaceae, in accordance with the three most invasive families worldwide [95]. The rapid growth and high reproduction rates of annual plant species and their capacity to resist unfavourable periods in the form of seeds makes them more suitable to develop in disturbed open spaces by fire, ploughing, or grazing [96, 97]. Poaceae and Fabaceae are typical families associated with livestock grazing and crop cultivation practices while Asteraceae take advantage in spreading mechanisms and dispersal ability [98]. On the contrary, native flora in the rest of Mediterranean regions lacked adaptations to continuous grazing and other disturbances such as fire; thus, native species have resulted negatively affected with the introduction of livestock and crops and the alteration of fire regimes, which have favoured the establishment of exotic species [73, 75, 99, 100].

The factor determining which exotic species became naturalised in a new area depended on the scale of analysis. At a broad scale (i.e. continental), it has been reported that climate determined the possibilities of exotic species establishment because of the significant biogeographical association existing between the climates in the source and the recipient regions [101]. Therefore, the similarity of the climate in source and recipients areas played a crucial role in the current distribution of exotic species [102–105]. The species' climatic tolerance was essential to successfully establish in the new region which highlighted the importance of co-adaptive mechanisms.

Additionally, habitat characteristics of the source area (climate, soil nutrient status, propagule pressure, disturbance, and remarkably human activities) determined the communities' potential to act as main donors of exotic species [101]. However, the relative importance of those factors ultimately depended upon the climate of the recipient region and the distribution of the main land uses which highlighted the importance of human pressure as a driver of exotic species distribution [106].

Species that can potentially colonise new areas undergo environmental filtering. Regarding abiotic filters (climate- and edaphic-related) acting at a regional scale, previous reports suggested a filtering process in both the source and the recipient areas but acting with different intensity in each of them [107]. Existing literature stated that the influence of abiotic factors was stronger in the recipient area, where especially the climate determined the successful naturalisation of exotic species [107], agreeing with previous reports about invasibility [108–110]. For example, in the Mediterranean region of central Chile, the increase in species richness with precipitation, and with the shortening of summer drought, was greater for exotic than for native species [107]. Therefore, exotic species naturalisation appeared enhanced by an improvement in the main limiting resource (water) (supported by the 'resource availability hypothesis') [103, 111, 112]. In the recipient area, not only abiotic filters but also biotic ones can be acting as filters, for example, plant-plant interactions occurring along the processes of plant community's secondary succession [113–115]. Possible processes between exotic and native species in the invaded area could be competence, tolerance, or facilitation; as a consequence, the relationship observed between both species groups would be negative, neutral, or positive, respectively. However, sometimes, this relationship appears conspicuous; the 'invasion paradox' stated that the relationship between species richness of native and exotic flora depends on the scale of study (being negative at small spatial scales $< 10 \text{ m}^2$ and positive at larger spatial scales $> 10 \text{ m}^2$) [116]. At the ecological community level, a consensus on the general impact of exotic species diversity has not been reached yet.

4. Positive relationships between native and exotic species in the Mediterranean biome

Although the frequency of exotic species in Mediterranean ecosystems is considerable, it varies among different regions [117] and types of studied system. Habitats with a higher degree of invasion are usually those related to anthropogenic activities [118] in terms of both, human population density and human-mediated disturbances [119]. Disturbances open a window of opportunity that promotes exotic species success by altering the environmental and soil conditions as well as by establishing new interactions within the native plant community [120]. For example, exotic species appeared associated with disturbed biological soil crusts [121], agrarian practices [122], grazing land use (e.g. 87.5% of the species significantly associated with continuously grazed grasslands in Southern Australia were exotic [123]), and fire events—the latter especially in California [120, 124]. Thus, better understanding of the influence of exotic species on native diversity is highly relevant to the management of Mediterranean ecosystems. However, a publication bias towards studies focusing on biologi-

cal invasions by exotic species with negative impacts [125], especially in ecological terms, has been common within the scientific community. For example, in Mediterranean grasslands, invasion by exotic species has been frequently cited as a key threat responsible for decreased native abundance, richness, growth and regeneration [126–128], and altered species composition [128]. Although the scientific community is aware of reports about serious negative impacts in ecology [129, 130], economy [34, 35], and society [131], studies focusing on the possible benefits that exotic species can provide have been overlooked receiving much less attention [132–134]. Fortunately, over the past years, the bias in the literature towards negative impacts from exotic species has started to revert. Positive associations between exotics and natives have recently been reported, especially in the Mediterranean biome. Here, the findings of some of the most outstanding studies reporting positive relationships are summarised.

In terms of richness, positive correlations between native and exotic species have been reported in all the Mediterranean regions. In central Chile, positive relationships were found in both shrublands [135] and grasslands [107, 122]. Similar relationships were also documented in the Californian shrublands [123] and for post-fire vegetation communities in the Californian *chaparral* [124, 136] and grasslands [137]. In the Mediterranean basin, positive correlations between native and exotic species were also found on different systems such as floodplains [138] and marine benthos communities [139].

Controlling for the environmental conditions and land uses has been proposed as key important steps when assessing relationships between natives and exotics at a broad scale. When including environmental variability, positive relationships were found in South Australian grasslands in terms of species richness, cover, and Shannon diversity index [140]. In the Mediterranean basin, common anthropic factors such as landscape heterogeneity and human pressure partially explained both native and exotic richness, but a significant percentage remained unexplained, revealing that biotic interactions between both species groups might be occurring [141].

Some studies that were not conducted in the Mediterranean biome stated that exotic species established in early successional stages impeded the re-establishment of native ones [142–144]. Contrarily, no apparent competition between both species groups has been reported along secondary succession in grasslands of central Chile and post-fire Californian plant communities [122, 124, 145]. Rather, in Ref. [122] a complementary role between native and exotic species possibly as a consequence of niche segregation at a local scale in earlier stages of succession was documented. Whereas time since the disturbing event had a positive effect on native species richness, exotic species richness and cover increased right after the disturbance and then richness remained stable until the end of the chronosequence while cover decreased [122, 140]. The increase in vegetation cover associated with the early colonisation by exotics seemed to create the appropriate conditions for the successful re-establishment of native species, which increased in number. Thus, exotic species acted as passengers [146] or even as facilitator species, playing a complementary role to the natives' one. In central Chile and Southern Australia, the coexistence under the conditions of extensive livestock grazing was achieved through two different strategies: alien species were mainly grazing-tolerant species, whereas native species were grazing-defensive species [94, 122, 140].

Other positive effects of exotic species in native communities have been shown in other systems or for other type of species. For example, an exotic nitrogen-fixing shrub was able to build up an island of fertility under its canopy by accumulating considerable stocks of C, N, and P in the soil and by improving the soil hydrological properties [147]. Likewise, the presence of another exotic species, *Lantana camara*, also improved soil quality [148].

Regarding effects of exotics on germination rates or seedling growth of native species in grasslands, the presence of the invasive species *Thymus vulgaris* originated in the Mediterranean basin that presents allelopathy showed no negative effect [149]. Moreover, facilitative effects on the reproductive success of co-flowering native plants have been reported in the presence of the invasive weed *Oxalis pescaprae* [150]. Likewise, it has been shown that litter of invasive exotic plants facilitated growth of the dominant native plants by altering soil moisture in Californian shrublands [151]. Additionally, in some cases, the presence of exotic plant species facilitated the visit of pollinators to native species [152]. In central Chile, alien European rabbits filled a role similar to the one played by native mammals, by dispersing native seeds [153].

Recent studies even showed that certain invasive species have become keystones for the survival of local endemisms. Therefore, eradication programmes to re-establish the original vegetation might provoke severe local extinction of endemic species [127, 154], population bottlenecks, and cascading effects across trophic levels [126, 155], as well as on pollinator communities [150]. Some exotic species can contribute to achieve native species conservation policies [133]; sometimes, even the employment of exotic species has been proposed as an effective action for ecological restoration [156, 157].

Many of the results reviewed here pointed out that exotic species coming from the Mediterranean basin were pre-adapted to the environmental conditions and land-use management in the recipient regions. Similarly, it has been shown that once they got naturalised in a non-native environment, they formed mixed native/exotic plant communities due to effective mechanisms of tolerance and facilitation that allow the coexistence between both species groups. This coexistence did not seem to be aggressive in opposition to the traditional beliefs that aliens' naturalisation always decreases native biodiversity [158] or displaces it by exclusion [49]. On the contrary, the coexistence between native and exotic species appears to be smooth as exotics seem to ameliorate the harsh environmental conditions created after a disturbance so that natives can re-establish in that area.

5. Towards a new paradigm

As reported here, many positive interactions between exotic and native assets have been described over the past decades. It seems therefore that it is time to rethink the traditional paradigm which, by default, considers exotic species as a threat for Mediterranean-type ecosystems. It would be desirable the employment of neutral terminology such as nonindigenous species to avoid negative predisposition to the effect of exotic species [159]. In fact, it has been reported that the perception of the consequences that exotic species have varies among different stakeholders [160]. Stakeholders with different socio-cultural contexts have very different

opinions about exotic species; some of them recognise the benefits of exotic species not only on the native flora at local scale but also on other species they have established relationships with [154], on the ecosystem services [124], on the human wellbeing [161], on the local and global economy [127], and so on. Thus, the crucial importance of adopting a more balanced view of exotic species and understanding their presence in a new area as a holistic process [162] need to be highlighted.

Assessing the functional roles that exotics may have established in their new areas to avoid unexpected results from incorrect management and being critical and open minded to find any possible mutualistic interactions between exotics and natives are crucial. In the foreseeable future, it would be desirable to evaluate in detail other possible facilitation processes between natives and exotics by studying plant-plant interactions. Future outcomes could also include the combination of the current ecological knowledge in invasion processes with forthcoming global change scenarios [37]. Merging the prospection of future climate change [8], landscape heterogeneity, land-use shifts, and the subsequent modelled displacement of exotic plant species distribution with current knowledge on invasive processes would be a fruitful study for determining areas which are more prone to invasion.

Evaluating the factors involved in naturalisation and invasion processes is key to accomplish the objectives of the Millennium Ecosystem Assessment Program [163]. The species reshuffling and its impact on the native plant communities undoubtedly contribute to the emergence of new environmental scenarios. These new scenarios have ecological and socioeconomic repercussions that are difficult to evaluate short term [164] or at a determined spatial scale. As multi-scale patterns are determinant of naturalisation success, evaluations should be conducted from broader to finer geographical scales and in the short, medium, and especially in long term [165]. To that end, we should take a comprehensive and systemic approach, coming to understand that fundamental ecology is context dependent, being tightly bound up to the social-cultural history, the anthropic activity, the economic implications, and the social tradeoffs [124]. Thus, it is necessary to accomplish transdisciplinary decision-making processes [166] which take into account not only ecological consequences but also ecosystem services and human well-being [167].

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Author details

Irene Martín-Forés

Address all correspondence to: imfores@pdi.ucm.es

Complutense University of Madrid, Madrid, Spain

References

- [1] Steffen W, Andreae MO, Bolin B, Cox PM, Crutzen PJ, Cubasch U, Held H, Nakicenovic N, Scholes RJ, Talaue-McManus L, Turner II BL. The Achilles' heels of the Earth system. *Environment*. 2004;**46**:9-20
- [2] Schellnhuber HJ, Crutzen PJ, Clark WC, Hunt J. Earth system analysis for sustainability. *Environmental: Science and Policy for Sustainable Development*. 2005;**47**:10-25
- [3] Crutzen PJ. Geology of mankind. *Nature*. 2002;**415**:23-23
- [4] Margalef R. *Ecología*. 9th ed. Omega: Barcelona; 1998. 951 p.
- [5] Pineda FD, Schmitz MF, Acosta-Gallo B, Fernández Pastor M, Arnaiz C, Díaz P, Ruiz-Labourdette D. Informe y síntesis de la actividad investigadora desarrollada en el marco de la Red de Seguimiento del Cambio Global (RSCG) en los Parques Nacionales españoles (RPN). Madrid: Fundación Biodiversidad. Convenio Organismo Autónomo Parques Nacionales (OAPN) – Oficina Española del Cambio Climático (OECC) – Fundación Biodiversidad (FB) – Agencia Española de Meteorología (AEMT); 2014.
- [6] Acosta-Gallo B. Comportamiento de los componentes aéreo y subterráneo de pastizales en diferentes condiciones ambientales [thesis]. Faculty of Biology, Complutense University of Madrid; 2005.
- [7] Vitousek PM. Beyond global warming: Ecology and global change. *Ecology*. 1994;**75**: 1861-1876
- [8] IPCC. Pachauri RK, Meyer LA, editors. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland; 2014. 151 p
- [9] Malone TF, Roederer JG. *Global Change*. ICSU Press: Cambridge; 1984
- [10] Vitousek PM, D'Antonio CM, Loope LL, Rejmánek M, Westbrooks R. Introduced species: A significant component of human-caused global change. *New Zealand Journal of Ecology*. 1997;**21**:1-1
- [11] Palang H, Mander Ü, Naveh Z. Holistic landscape ecology in action. *Landscape and Urban Planning*. 2000;**50**:1-6
- [12] Lev-Yadun S, Gopher A, Abbo S. The cradle of agriculture. *Science*. 2000;**288**:1602-1603
- [13] Zeder MA. Domestication and early agriculture in the Mediterranean Basin: Origins, diffusion, and impact. *Proceedings of the National Academy of Sciences of the United States of America*. 2008;**105**:11597-11604
- [14] Estévez J. Study of the faunal remains (original in Spanish). In: Fosca C, Olaria C, editors. *Servicio de Publicaciones Diputación de Castellón*. Spain: Castellón; 1988. pp. 281-337
- [15] Boessneck J, von den Driesch A. Finds of animal bones from four caves in southern Spain (original in German). In: Boessneck J, von den Driesch A, editors. *Studies on Finds of Early Animal Bones from the Iberian Peninsula 7*. Munich: Institut für Palaeoanatomir, Domestikationsforschung und Geschichte de Tiermedizin der Universität München; 1980. pp. 1-83

- [16] Brown TA, Jones AK, Powell W, Allaby RG. The complex origins of domesticated crops in the fertile Crescent. *Trends in Ecology and Evolution*. 2008;**24**:103-109
- [17] Preston CD, Pearman DA, Hall AR. Archaeophytes in Britain. *Botanical Journal of the Linnean Society*. 2004;**145**:257-294
- [18] Cronk QCB, Fuller JL. *Plant invaders: The Threat to Natural Ecosystems*. Chapman and Hall: London; 1995. 256 p
- [19] National Geographic Society. 1491: America Before Columbus. William Reese Company;1991. 154 p
- [20] Hulme PE. Trade, transport and trouble: Managing invasive species pathways in an era of globalization. *Journal of Applied Ecology*. 2009;**46**:10-18
- [21] Baier SL, Bergstrand JH. The growth of world trade: Tariffs, transport costs, and income similarity. *Journal of International Economics*. 2001;**53**:1-27
- [22] Hall CM. Tourism and biological exchange and invasions: A missing dimension in sustainable tourism? *Tourism Recreation Research*. 2015;**40**:81-94
- [23] Pieterse JN. *Globalization and Culture: Global Mélange*. USA: Lanham MD, Rowman & Littlefield; 2015. 219 p
- [24] Levine JM, D'Antonio CM. Forecasting biological invasions with increasing international trade. *Conservation Biology*. 2003;**17**:322-326
- [25] Perrings C, Dehnen-Schmutz K, Touza J, Williamson M. How to manage biological invasions under globalization. *Trends in Ecology and Evolution*. 2005;**20**:212-215
- [26] Meyerson LA, Mooney HA. Invasive alien species in an era of globalization. *Frontiers in Ecology and the Environment*. 2007;**5**:199-208
- [27] Bradley BA, Blumenthal DM, Early R, Grosholz ED, Lawler JJ, Miller LP, Sorte CJB, D'Antonio CM, Diez JM, Dukes JS, Ibañez I, Olden JD. Global change, global trade, and the next wave of plant invasions. *Frontiers in Ecology and the Environment*. 2012;**10**:20-28
- [28] Paskoff R, Manríquez H. Ecosystem and legal framework for coastal management in central Chile. *Ocean and Coastal Management*. 1999;**42**:105-117
- [29] Rouget M, Richardson DM, Cowling RM, Lloyd JW, Lombard AT. Current patterns of habitat transformation and future threats to biodiversity in terrestrial ecosystems of the Cape Floristic Region, South Africa. *Biological Conservation*. 2003;**112**:63-85
- [30] Dukes JS, Mooney HA. Disruption of ecosystem processes in western North America by invasive species. *Revista Chilena de Historia Natural*. 2004;**77**:411-437
- [31] Schwartz MW, Thorne JH, Viers JH. Biotic homogenization of the California flora in urban and urbanizing regions. *Biological Conservation*. 2006;**187**:282-291
- [32] Vitousek PM, D'Antonio CM, Loope LL, Westbrooks R. Biological invasions as global environmental change. *American Scientist*. 1996;**84**:468-478
- [33] Pimentel D, Zuniga R, Morrison D. Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics*. 2005; **52**:273-288.

- [34] Pimentel D, McNair S, Janecka J, Wightman J, Simmonds C, O'Connell C, Wong E, Russel L, Zern J, Aquino T, Tsomondo T. Economic and environmental threats of alien plant, animal, and microbe invasions. *Agriculture, Ecosystems and Environment*. 2001;**84**:1-20
- [35] Pimentel D, Zuniga R, Morrison D. Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics*. 2005;**52**:273-288
- [36] Mack RN, Simberloff D, Lonsdale WM, Evans H, Clout M, Bazzaz FA. Biotic invasions: Causes, epidemiology, global consequences, and control. *Ecological Applications*. 2000;**10**:689-710
- [37] Sala OE, Chapin FS III, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, LeRoy Poff N, Sykes MT, Walker BH, Walker M, Wall DH. Global biodiversity scenarios of the year 2100. *Science*. 2000;**287**:1770-1774
- [38] MA (Millennium Ecosystem Assessment). *Ecosystems and Human Well-Being: A Framework for Assessment*. Island Press: Washington DC; 2003
- [39] Corvalan C, Hales S, McMichael A. *Ecosystems and Human Well-being: Health Synthesis [a report for the Millennium Ecosystem Assessment]*. Geneva: World Health Organization; 2005
- [40] Díaz S, Fargione J, Chapin FS III, Tilman D. Biodiversity loss threatens human well-being. *PLoS Biology*. 2006;**4**:e277
- [41] Martín-López B, Gómez-Baggethun E, González JA, Lomas PL, Montes C. The assessment of ecosystem services provided by biodiversity: Rethinking concepts and research needs. In: Aronoff JB, editor. *Handbook of Nature Conservation: Global, Environmental and Economic Issues*. Nova Science Publisher Inc. New York, USA; 2009. 479 p
- [42] Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings C, Venail P, Narwani A, Mace GM, Tilman D, Wardle DA, Kinzig AP, Daily GC, Loreau M, Grace JB, Larigauderie A, Srivastava DS, Naeem S. Biodiversity loss and its impact on humanity. *Nature*. 2012;**486**:59-67
- [43] Mace GM, Norris K, Fitter AH. Biodiversity and ecosystem services: A multilayered relationship. *Trends in Ecology and Evolution* 2012;**27**:19-26
- [44] Brock JH, Wade M, Pyšek P, Green D. *Plant Invasions: Studies from North America and Europe*. Leiden: Backhuys; 1997
- [45] Luken JO, Thieret JW. *Assessment and Management of Plant Invasions*. New York: Springer; 1997
- [46] Dukes JS, Mooney HA. Does global change increase the success of biological invaders? *Trends in Ecology and Evolution*. 1999;**14**:135-139
- [47] Higgins SI, Richardson DM, Cowling RM, Trinder-Smith TH. Predicting the landscape scale distribution of alien plants and their threat to plant diversity. *Conservation Biology*. 1999;**13**:303-313

- [48] Richardson DM, Pyšek P, Rejmánek M, Barbour MG, Panetta FD, West CJ. Naturalization and invasion of naturalized plants: Concepts and definitions. *Diversity and Distributions*. 2000;**6**:93-107
- [49] Winter M, Schweigera O, Klotza S, Nentwig W, Andriopoulos P, Arianoutsou M, Basnoue C, Delipetrou P, Didžiulis V, Hejdah M, Hulme PE, Lambdon JW, Pergl J, Pyšek P, Royl DB, Kühn I. Plant extinctions and introductions lead to phylogenetic and taxonomic homogenization of the European flora. *Proceedings of the National Academy of Sciences of the United States of America*. 2009;**106**:21721-21725
- [50] Figueroa JA, Teillier S, Castro SA. Diversity patterns and composition of native and exotic floras in central Chile. *Acta Oecologica*. 2011;**37**:103-109
- [51] Blossey B. Before, during and after: The need for long-term monitoring in invasive plant species management. *Biological Invasions*. 1999;**1**:301-311
- [52] Zavaleta ES, Hobbs RJ, Mooney HA. Viewing invasive species removal in a whole-ecosystem context. *Trends in Ecology and Evolution*. 2001;**16**:454-459
- [53] Pyšek P, Richardson DM. Invasive species, environmental change and management, and health. *Annual Review of Environment and Resources*. 2010;**35**:25-55
- [54] Barbier EB, Knowler D, Gwatipeda J, Reichard SH, Hodges AR. Implementing policies to control invasive plant species. *BioScience*. 2013;**63**:132-138
- [55] Essl F, Dullinger S, Rabitsch W, Hulme PE, Wilson JR, Richardson DM. Delayed biodiversity change: no time to waste. *Trends in Ecology and Evolution*. 2015;**30**:375-378
- [56] Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J. Biodiversity hotspots for conservation priorities. *Nature*. 2000;**403**:853-858
- [57] CBD. Global Biodiversity Outlook 4. Montreal: Secretariat of the Convention on Biological Diversity; 2014
- [58] Hulme PE. Invasion pathways at a crossroad: Policy and research challenges for managing alien species introductions. *Journal of Applied Ecology*. 2015;**52**:1418-1424.
- [59] Balmford A, Moore JL, Brooks T, Burgess N, Hansen LA, Williams P, Rahbek C. Conservation conflicts across Africa. *Science*. 2001;**291**:2616-2619
- [60] Lionello P, Malanotte-Rizzoli P, Boscolo R, Alpert P, Artale V, Li L, Luterbacher J, May W, Trigo R, Tsimplis M, Ulbrich U, Xoplaki E. The Mediterranean climate: An overview of the main characteristics and issues. *Developments in Earth and Environmental Sciences*. 2012;**4**:1-26
- [61] Reale O, Dirmeyer P. Modeling the effects of vegetation on Mediterranean climate during the Roman classical period: Part I: Climate history and model sensitivity. *Global Planet*. 2000;**25**:163-184
- [62] Reale O, Shukla J. Modeling the effects of vegetation on Mediterranean climate during the Roman classical period: Part II: Model simulation. *Global Planet*. 2000;**25**:185-214

- [63] Dümenil-Gates L, Liess S. Impacts of deforestation and afforestation in the Mediterranean region as simulated by the MPI atmospheric GCM. *Global and Planetary Change*. 2001;**30**:309-328
- [64] Wade TG, Riitters KH, Wickham JD, Jones KB. Distribution and causes of global forest fragmentation. *Conservation Ecology*. 2003;**7**:7
- [65] Pineda FD, Schmitz MF, Hernández S. Interacciones entre infraestructuras y conectividad natural del paisaje. I Congreso Ingeniería Civil, Territorio y Medio Ambiente. Col. Ing. CC y Puertos, Madrid; 2002
- [66] Schmitz MF, Pineda FD, Castro H, de Aranzabal I, Aguilera P. Cultural landscape and socioeconomic structure. Environmental value and demand for tourism in a Mediterranean territory. Sevilla: Junta de Andalucía; 2005
- [67] Di Castri F. Mediterranean-type shrublands of the world. In: Di Castri F, Goodall DW, Specht RL, editors. *Mediterranean-type Shrublands*. Amsterdam: Elsevier; 1981. pp. 1-52
- [68] Perevolotsky A, Seligman NG. Role of grazing in Mediterranean rangeland ecosystems— inversion of a paradigm. *BioScience*. 1998;**48**:1007-1017
- [69] Fox MD. Mediterranean weeds: Exchanges of invasive plants between the five Mediterranean regions of the world. In: Di Castri F, Hansen AJ, Debussche M, editors. *Biological Invasions in Europe and the Mediterranean Basin*. The Netherlands: Springer; 1990. pp. 179-200
- [70] Van de Wouw P, Echeverría C, Rey-Benayas JM, Holmgren M. Persistent Acacia savannas replace Mediterranean sclerophyllous forests in South America. *Forest Ecology and Management*. 2011;**262**:1100-1108
- [71] Turner BL, Gómez Sal A, González Bernáldez F, Di Castri F, editors. *Global Land Use Change. A Perspective from the Columbian Encounter*. Madrid, Espana: CSIC; 1995
- [72] Castro SA, Figueroa JA, Muñoz-Schick M, Jaksic FM. Minimum residence time, biogeographical origin, and life cycle as determinants of the geographical extent of naturalized plants in continental Chile. *Diversity and Distributions*. 2005;**11**:183-191
- [73] Holmgren M, Aviles R, Sierralta L, Segura AM, Fuentes ER. Why have European herbs so successfully invaded the Chilean matorral? Effects of herbivory, soil nutrients, and fire. *Journal of Arid Environment*. 2000;**44**:197-211
- [74] Pauchard A, Alaback PB. Influence of elevation, land use, and landscape context on patterns of alien plant invasions along roadsides in protected areas of south-central Chile. *Conservation Biology*. 2004;**18**:238-248
- [75] Del Pozo A, Ovalle C, Casado MA, Acosta B, De Miguel JM. Effects of grazing intensity in grasslands of the Espinal of central Chile. *Journal of Vegetation Science*. 2006;**17**:791-798
- [76] HilleRisLambers J, Yelenik SG, Colman BP, Levine JM. California annual grass invaders: The drivers or passengers of change? *Journal of Ecology*. 2010;**98**:1147-1156

- [77] Pauchard A, Cavieres L, Bustamante R. Comparing alien plant invasions among regions with similar climates: where to from here? *Diversity and Distributions*. 2004;**10**:371-375
- [78] Bouvier VM. *Women and the conquest of California, 1542-1840: Codes of silence*. University of Arizona Press. Tucson, Arizona, USA; 2004. 266p
- [79] Chidester D. *Religions of South Africa (Routledge Revivals)*. Routledge. London, UK; 2014. 306p
- [80] Milton SJ. Grasses as invasive alien plants in South Africa: Working for water. *South African Journal of Science*. 2004;**100**:69-75
- [81] Lines WJ. *Taming the Great South Land: A History of the Conquest of Nature in Australia*. University of California Press. Berkeley, California, USA; 1991
- [82] The Australian National Botanic Gardens. *Mallee Plants-surviving Harsh Conditions*. Acton: Education Services Australian National Botanic Gardens; 2004
- [83] Le Houérou NH. Plant invasion in the rangelands of the isoclimatic Mediterranean zone. In: Groves RH, Di Castri F, editors. *Biogeography of Mediterranean Invasions*. Camebridge: Cambridge University Press; 1991. pp. 393-404
- [84] Kruger FJ, Breytenbach GJ, Macdonald IAW, Richardson DM. The characteristics of invaded Mediterranean-climate regions. In: Drake JA, Mooney, HA, Di Castri F, Groves RH, Kruger FJ, Rejmánek M, Williamson M, editors. *Biological Invasions: A Global Perspective*. New York, The USA: John Wiley & Sons; 1989. pp. 389-405
- [85] Groves RH, Di Castri F, editors. *Biogeography of Mediterranean Invasions*. Camebridge (UK): Cambridge University Press; 1991. 485 p
- [86] Tilman D. Community invasibility, recruitment limitation, and grassland biodiversity. *Ecology*. 1997;**78**:81-92
- [87] Zobel M, Otsus M, Liira J, Moora M, Möls T. Is small-scale species richness limited by seed availability or microsite availability? *Ecology*. 2000;**81**:3274-3282
- [88] Jauni M, Gripenberg S, Ramula S. Non-native plant species benefit from disturbance: A meta-analysis. *Oikos*. 2015;**124**:122-129
- [89] Prinzing A, Durka W, Klotz S, Brandl R. Which species become aliens? *Evolutionary Ecology Research*. 2002;**4**:385-405
- [90] Arianoutsou M, Delipetrou P, Vilà M, Dimitrakopoulos PG, Celesti-Grapow L, Wardell-Johnson G, Henderson L, Fuentes N, Ugarte-Mendes NE, Rundel PW. Comparative patterns of plant invasions in the Mediterranean Biome. *Plos One*. 2013;**8**:1-13
- [91] Saul WC, Jeschke JM, Heger T. The role of eco-evolutionary experience in invasion success. *NeoBiota*. 2013;**17**:57-74
- [92] Holmgren M. Exotic herbivores as drivers of plant invasions and switch to ecosystem alternative states. *Biological Invasions*. 2002;**4**:25-33

- [93] Ricotta C, La Sorte FA, Pyšek P, Rapson GL, Celesti-Grapow L, Thompson K. Phyloecology of urban alien floras. *Journal of Ecology*. 2009;**97**:1243-1251
- [94] De Miguel JM, Casado MA, Del Pozo A, Ovalle C, Moreno-Casasola P, Travieso-Bello AC, Barrera M, Ricardo N, Tecco PA, Acosta B. How reproductive, vegetative and defensive strategies of Mediterranean grassland species respond to a grazing intensity gradient. *Plant Ecology*. 2010;**210**:97-110
- [95] Pyšek P. Is there a taxonomic pattern to plant invasions? *Oikos*. 1998;**82**:282-294
- [96] Le Floch E. Invasive plants of the Mediterranean Basin. In: Groves RH, Di Castri F, editors. *Biogeography of Mediterranean Invasions*. Cambridge (UK): Cambridge University Press; 1991. pp. 67-80
- [97] Gómez-González S, Torres-Díaz C, Valencia G, Torres-Morales P, Cavieres LA, Pausas JG. Anthropogenic fires increase alien and native annual species in the Chilean coastal matorral. *Diversity and Distributions*. 2010;**17**:58-67
- [98] Venable DL. The evolutionary ecology of seed heteromorphism. *The American Naturalist*. 1985;**126**:577-595
- [99] Milchunas DG, Lauenroth WK. Quantitative effects of grazing on vegetation and soils over a global range of environments. *Ecological Monographs*. 1993;**63**:327-366
- [100] Ovalle C, Del Pozo A, Casado MA, Acosta B, De Miguel JM. Consequences of landscape heterogeneity on grassland diversity and productivity in the espinal agroforestry system of central Chile. *Landscape Ecology*. 2006;**21**:585-594
- [101] Casado MA, Acosta-Gallo B, Sánchez-Jardón L, Martín-Forés I, Castro I, Ovalle C, del Pozo A, de Miguel JM. Interactive effects of source and recipient habitats on plant invasions: Distribution of exotic species in Chile. *Diversity and Distributions*. 2015;**21**:609-619
- [102] Alpert P, Bone E, Holzapfel C. Invasiveness, invasibility and the role of environmental stress in the spread of non-native plants. *Perspectives in Plant Ecology, Evolution and Systematics*. 2000;**3**:52-66
- [103] Davis MA, Grime J, Thompson K. Fluctuating resources in plant communities: A general theory of invasibility. *Journal of Ecology*. 2000;**88**:528-534
- [104] Chytrý M, Maskell LC, Pino J, Pyšek P, Vilà M, Font X, Smart SM. Habitat invasions by alien plants: A quantitative comparison among Mediterranean, subcontinental and oceanic regions of Europe. *Journal of Applied Ecology*. 2008;**45**:448-458
- [105] Chytrý M, Pyšek P, Wild J, Pino J, Maskell L, Vilà M. European map of alien plant invasions based on the quantitative assessment across habitats. *Diversity and Distributions*. 2009;**15**:98-107
- [106] Marini L, Battisti A, Bona E, Federici G, Martini F, Pautasso M, Hulme PE. Alien and native plant life-forms respond differently to human and climate pressures. *Global Ecology and Biogeography*. 2012;**21**:534-544

- [107] Martín-Forés I, Sánchez-Jardón L, Acosta-Gallo B, Del Pozo A, Castro I, de Miguel JM, Ovalle C, Casado MA. From Spain to Chile: Environmental filters and success of herbaceous species in Mediterranean-climate regions. *Biological Invasions*. 2015;**17**:1425-1438
- [108] Kolar CS, Lodge DM. Progress in invasion biology predicting invaders. *Trends in Ecology and Evolution*. 2001;**16**:199-204
- [109] Dawson W, Burslem DF, Hulme PE. Factors explaining alien plant invasion success in a tropical ecosystem differ at each stage of invasion. *Journal of Ecology*. 2009;**97**:657-665
- [110] González-Moreno P, Diez JM, Ibáñez I, Font X, Vilà M. Plant invasions are context-dependent: Multiscale effects of climate, human activity and habitat. *Diversity and Distributions*. 2014;**20**:720-731
- [111] Cleland EE, Smith MD, Andelman SJ, Bowles C, Carney KM, Horner-Devine MC, Drake JM, Emery SM, Gramling JM, Vandermaast DB. Invasion in space and time: nonnative species richness and relative abundance respond to interannual variation in productivity and diversity. *Ecology Letters*. 2004;**7**:947-957
- [112] Richardson DM, Pyšek P. Plant invasions: Merging the concepts of species invasiveness and community invasibility. *Progress in Physical Geography*. 2006;**30**:409-431
- [113] Armas C, Pugnaire FI. Plant interactions govern population dynamics in a semi-arid plant community. *Journal of Ecology*. 2005;**93**:978-989
- [114] Armas C, Schöb C, Gutiérrez JR. Modulating effects of ontogeny on the outcome of plant-plant interactions along stress gradients. *New Phytologist*. 2013;**200**:7-9
- [115] Jeffers ES, Bonsall MB, Froyd CA, Brooks SJ, Willis KJ. The relative importance of biotic and abiotic processes for structuring plant communities through time. *Journal of Ecology*. 2015;**103**:459-472
- [116] Fridley JD, Stachowicz JJ, Naeem S, Sax DF, Seabloom EW, Smith MD et al. The invasion paradox: Reconciling pattern and process in species invasions. *Ecology*. 2007;**88**:3-17
- [117] Rejmánek M, Richardson DM, Pyšek P. *Plant Invasions and Invasibility of Plant Communities in Vegetation Ecology*. 2nd ed. Oxford (UK): John Wiley & Sons Ltd; 2013. pp. 387-424
- [118] Montserrat V, Joan P, Xavier F. Regional assessment of plant invasions across different habitat types. *Journal of Vegetation Science*. 2007;**18**:35-42
- [119] Estay SA, Navarrete SA, Toro SR. Effects of human mediated disturbances on exotic forest insect diversity in a Chilean Mediterranean ecosystem. *Biodiversity and Conservation*. 2012;**21**:3699-3710
- [120] Carvalho LM, Antunes PM, Martins-Loução MA, Klironomos JN. Disturbance influences the outcome of plant-soil biota interactions in the invasive *Acacia longifolia* and in native species. *Oikos*. 2010;**119**:1172-1180
- [121] Hernandez RR, Sandquist DR. Disturbance of biological soil crust increases emergence of exotic vascular plants in California sage shrub. *Plant Ecology*. 2011;**212**:1709

- [122] Martín-Forés I, Castro I, Acosta-Gallo B, del Pozo A, Sánchez-Jardón L, de Miguel JM, Ovalle C, Casado MA. Alien plant species coexist over time with native ones in Chilean Mediterranean grasslands. *Journal of Plant Ecology*. 2016;**9**:682-691
- [123] Price JN, Wong NK, Morgan JW. Recovery of understorey vegetation after release from a long history of sheep grazing in a herb-rich woodland. *Austral Ecology*. 2010;**35**:505-514
- [124] Guo Q. Temporal changes in native-exotic richness correlations during early post-fire succession. *Acta Oecologica*. 2017; **80**:47-50
- [125] Davis MA, Chew MK, Hobbs RJ, Lugo AE, Ewel JJ, Vermeij GJ, Brown JH, Rosenzweig ML, Gardener MR, Carroll SP, Thompson K, Pickett STA, Stromberg JC, Del Tredici P, Suding KN, Ehrenfeld JG, Grime JP, Mascaro J, Briggs JC. Don't judge species on their origins. *Nature*. 2011;**474**:153-154
- [126] Lenz TI, Moyle-Croft JL, Facelli JM. Direct and indirect effects of exotic annual grasses on species composition of a South Australian grassland. *Austral Ecology*. 2003;**28**:23-32
- [127] Gornish ES, Ambrozio dos Santos P. Invasive species cover, soil type, and grazing interact to predict long-term grassland restoration success. *Restoration Ecology*. 2015;**24**:222-229
- [128] Flory SL, Clay K. Non-native grass invasion alters native plant composition in experimental communities. *Biological Invasions*. 2010;**12**:1285-1294
- [129] Lowe S, Browne M, Boudjelas S, De Poorter M. 100 of the World's Worst Invasive Alien Species: A Selection from the Global Invasive Species Database. Auckland, New Zealand: Invasive Species Specialist Group; 2000. p. 12
- [130] McGeoch MA, Butchart SHM, Spear D, Marais E, Kleynhans EJ, Symes A, Chanson J, Hoffmann M. Global indicators of biological invasion: species numbers, biodiversity impact and policy responses. *Diversity and Distributions*. 2010;**16**:95-108
- [131] Pejchar L, Mooney HA. Invasive species, ecosystem services and human well-being. *Trends in Ecology and Evolution*. 2009;**24**:495-504
- [132] Rodríguez LF. Can invasive species facilitate native species? Evidence of how, when, and why these impacts occur. *Biological Invasions*. 2006;**8**:927-939
- [133] Schlaepfer MA, Sax DF, Olden JD. The potential conservation value of nonnative species. *Conservation Biology*. 2011;**25**:428-437
- [134] Pienkowski T, Williams S, McLaren K, Wilson B, Hockley N. Alien invasions and livelihoods: Economic benefits of invasive Australian red claw crayfish in Jamaica. *Ecological Economics*. 2015;**112**:68-77
- [135] Sax DF. Native and naturalized plant diversity are positively correlated in shrub communities of California and Chile. *Diversity and Distributions*. 2002;**8**:193-210
- [136] Guo Q. No consistent small-scale native–exotic relationships. *Plant Ecology*. 2015;**216**: 1225-1230

- [137] Seabloom EW, Harpole WS, Reichman OJ, Tilman D. Invasion, competitive dominance, and resource use by exotic and native California grassland species. *Proceedings of the National Academy of Sciences*. 2003;**100**:13384-13389
- [138] Aguiar FC, Ferreira MT, Albuquerque A. Patterns of exotic and native plant species richness and cover along a semi-arid Iberian river and across its floodplain. *Plant Ecology*. 2006;**184**:189-202
- [139] Çınar ME, Katagan T, Öztürk B, Dagli E, Açık S, Bitlis B, Bakır K, Doğan A. Spatio-temporal distributions of zoobenthos in Mersin Bay (Levantine Sea, eastern Mediterranean) and the importance of alien species in benthic communities. *Marine Biology Research*. 2012;**8**:954-968
- [140] Martín-Forés I, Guerin GR, Lowe AJ. Weed abundance is positively correlated with native plant diversity in grasslands of southern Australia. *PlosOne* (accepted)
- [141] Bartomeus I, Sol D, Pino J, Vicente P, Font X. Deconstructing the native-exotic richness relationship in plants. *Global Ecology and Biogeography*. 2012;**21**:524-533
- [142] Kulmatiski A. Exotic plants establish persistent communities. *Plant Ecology*. 2006;**187**: 261-275
- [143] Vilà M, Espinar JL, Hejda M, Hulme PE, Jarošík V, Maron JL, Pergl J, Schaffner U, Sun Y, Pyšek P. Ecological impacts of invasive alien plants: A metaanalysis of their effects on species, communities and ecosystems. *Ecology Letters*. 2011;**14**:702-708
- [144] Tognetti PM, Chaneton EJ. Invasive exotic grasses and seed arrival limit native species establishment in an old-field grassland succession. *Biological Invasions*. 2012;**14**: 2531-2544
- [145] Kimball S, Goulden ML, Suding KN, Parker S. Altered water and nitrogen input shifts succession in a southern California coastal sage community. *Ecological Applications*. 2014;**24**:1390-1404
- [146] MacDougall AS, Turkington R. Are invasive species the drivers or passengers of change in degraded ecosystems? *Ecology*. 2005;**86**:42-55
- [147] Stinca A, Chirico GB, Incerti G, Bonanomi G. Regime shift by an exotic nitrogen-fixing shrub mediates plant facilitation in primary succession. *Plos One*. 2005;**10**:e0123128
- [148] Patel S. A weed with multiple utility: *Lantana camara*. *Reviews in Environmental Science and Bio/Technology*. 2011;**10**:341-351
- [149] Nielsen JA, Frew RD, Whigham PA, Callaway RM, Dickinson KJM. Germination and growth responses of co-occurring grass species to soil from under invasive *Thymus vulgaris*. *Allelopathy Journal*. 2015;**35**:139-152
- [150] Ferrero V, Castro S, Costa J, Acuna P, Navarro L, Loureiro J. Effect of invader removal: Pollinators stay but some native plants miss their new friend. *Biological invasions*. 2013;**15**:2347-2358

- [151] Bartomeus I, Vilà M, Santamaría L. Contrasting effects of invasive plants in plant–pollinator networks. *Oecologia*. 2008;**155**:761-770
- [152] Castro SA, Bozinovic F, Jaksic FM. Ecological efficiency and legitimacy in seed dispersal of an endemic shrub (*Lithrea caustica*) by the European rabbit (*Oryctolagus cuniculus*) in central Chile. *Journal of Arid Environments*. 2008;**72**:1164-1173
- [153] Wolkovich EM, Bolger DT, Cottingham KL. Invasive grass litter facilitates native shrubs through abiotic effects. *Journal of Vegetation Science*. 2009;**20**:1121-1132
- [154] Van Riel P, Jordaens K, Martins AMF, Backeljau T. Eradication of exotic species. *Trends in Ecology and Evolution*. 2000;**15**:515
- [155] Courchamp F, Caut S, Bonnaud E, Bourgeois K, Angulo E, Watari Y. Eradication of alien invasive species: surprise effects and conservation successes. In: Veitch CR, Clout MN, Towns DR, editors. *Island Invasives: Eradication and Management*. Gland, Switzerland: IUCN; 2011. pp. 285-289
- [156] Jeddi K, Chaieb M. Restoring degraded arid Mediterranean areas with exotic tree species: Influence of an age sequence of *Acacia salicina* on soil and vegetation dynamics. *Flora-Morphology, Distribution, Functional Ecology of Plants*. 2012;**207**:693-700
- [157] Bussotti F, Pollastrini M, Holland V, Brüggemann W. Functional traits and adaptive capacity of European forests to climate change. *Environmental and Experimental Botany*. 2015;**111**:91-113
- [158] Davis MA. Biotic globalization: does competition from introduced species threaten biodiversity? *Bioscience*. 2003;**53**:481-489
- [159] Colautti RI, MacIsaac HJ. A neutral terminology to define ‘invasive’ species. *Diversity and Distributions*. 2004;**10**:135-141
- [160] García-Llorente M, Martín-López B, González JA, Alcorlo P, Montes C. Social perceptions of the impacts and benefits of invasive alien species: Implications for management. *Biological Conservation*. 2008;**141**:2969-2983
- [161] Shackleton S, Kirby D, Gambiza J. Invasive plants – friends or foes? Contribution of prickly pear (*Opuntia ficus-indica*) to livelihoods in Makana Municipality, Eastern Cape, South Africa. *Development Southern Africa*. 2011;**28**:177-193
- [162] Schlaepfer MA, Sax DF, Olden JD. Toward a more balanced view of non-native species. *Conservation Biology*. 2012;**26**:1153-1158
- [163] Carpenter S, Mooney HA, Agard J, Capistrano D, DeFries RS, Díaz S, Dietz T, Duraipappah AK, Oteng-Yeboah A, Pereira EM, Perrings C, Rield WV, Sarukhan J, Schies RJ, Whyte A. Science for managing ecosystem services: Beyond the millennium assessment. *Proceedings of the National Academy of Science of the United States of America*. 2009;**106**:1305-1312
- [164] Rockstrom J, Steffen W, Noone K, Persson Å, Chapin I FS, Lambin EF, Lenton TM, Scheffer M, Folke C, Schellnhuber HJ, Nykvist B, De Wit CA, Huges T, Van Der Leeuw S,

- Rodhe H, Sörlin S, Snyder PK, Costanza R, Svedin U, Falkenmark M, Karlberg L, Corell RW, Fabry VJ, Hansen J, Walker B, Liverman D, Richardson K, Crutzen P, Foley JA. A safe operating space for humanity. *Nature*. 2009;**461**:472-475
- [165] Strayer DL, Eviner VT, Jeschke JM, Pace ML. Understanding the long-term effects of species invasions. *Trends in Ecology and Evolution*. 2006;**21**:645-651
- [166] Seastedt TR, Hobbs RJ, Suding KN. Management of novel ecosystems: Are novel approaches required? *Frontiers in Ecology and the Environment*. 2008;**6**:547-553
- [167] Bennett EM, Cramer W, Begossi A, Cundill G, Díaz S, Egoh BN, Geijzenborffer IR, Krug CB, Lavorel S, Lazos E, Lebel L, Martín-López B, Meyfroidt P, Mooney HA, Nel JL, Pascual U, Payet K, Harguindeguy NP, Peterson GD, Prieur-Richard AH, Reyers B, Roebeling P, Seppelt R, Solan M, Tschakert P, Tschardt T, Turner II BL, Verburg PH, Viglizzo EF, White PCL, Woodward G. Linking biodiversity, ecosystem services, and human well-being: Three challenges for designing research for sustainability. *Current Opinion in Environmental Sustainability*. 2015;**14**:76-85