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# What we can learn from the current vegetation for forest restoration in the Mediterranean region - a case study from the island of Asinara

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## Abstract

Forests worldwide suffer from over-utilization, clearing and degradation. In the Mediterranean region, human activities have almost completely transformed native vegetation into secondary communities, leaving mostly fragmented woodlands within cultural landscapes. Those secondary habitats are often highly diverse. However, forests are key ecosystems that fulfill multiple ecosystem services, such as provision of habitats for a variety of species. Taking the island and National Park of Asinara (NW Sardinia, Italy) as an example, we address the controversy of the maintenance of open cultural landscapes and forest restoration efforts. This paper aims to compare the relative value of open to forest habitats for the provision of ecosystem services related to biodiversity. We further propose scenarios regarding forest development for Asinara Island, giving implications for implementation and management. To assess plant diversity and natural tree regeneration we conducted plot-based vegetation surveys. A germination trial was performed to evaluate the potential of the soil seed bank. Our study shows, that several secondary habitats are characterized by a high phytodiversity but that forest remnants play a crucial role regarding overall biodiversity. Since the remaining forest is highly fragmented and natural regeneration of tree species is very low management measures are needed. We therefore suggest to extend the forest area on Asinara Island by connecting remnants as initial points but also to maintain secondary habitats to obtain a heterogenic landscape mosaic. Trees will have to be introduced by seeding or planting and need special care due to water shortage, grazing pressure and insect herbivory.

## Introduction

In many ecoregions throughout the world, forests are key ecosystems with manifold ecological functions, fulfilling a broad range of ecosystem services. Forests produce timber and non-timber products, act as carbon sinks and stabilize the climate, prevent soils from erosion, are important habitats for many plant and animal species, and provide services for human health and wellbeing (Zerbe 2009; Harrison et al. 2010; Nowak et al. 2014; Luque & Iverson 2016). Notwithstanding, forests have globally suffered from clearance, overexploitation, and degradation (FAO 2011; Kissinger et al. 2012). Forest degradation has led to a severe loss of biodiversity (Brooks et al. 2006; Barlow et al. 2016). Therefore, forest restoration is seen as an important practice to promote biodiversity and restore important ecosystem services (Zerbe 2009; Brudvig 2011). However, particularly throughout Europe, hundreds to thousands years of land-use practices have created species-rich cultural landscapes, which also contribute to a higher (global) biodiversity (Anders et al. 2004; Zerbe et al. 2009). In those cases, it is questionable if forest restoration should be *per se* a primary goal considering nature and biodiversity conservation.

The Mediterranean region is a good example where land-use practices over several millenia transformed nearly all of the native vegetation into secondary or semi-natural habitats, often with a high value regarding cultural history and nature conservation (Blondel 2006; Naveh 2007). The influence of human activities has resulted in highly heterogeneous landscapes which are characterized by patches of different land-use and natural habitats (Naveh 1994; Burel & Baudry 1995). This age-old adaptation to human activities and environmental conditions has often been associated with the high biodiversity of the Mediterranean region (Naveh 1994; Farina 1997).

The Millennium Ecosystem Assessment (MEA 2005) reported that about 70% of the native Mediterranean ecosystems have been transformed into non-native ones. Of the natural forest ecosystems only about 9.4% is left, most of them in different stages of degradation (Arianoutsou et al. 2012). The traditionally regarded climax vegetation of the Mediterranean Basin is indicated by evergreen forests differentiated by different oak trees (Blasi 2010). These evergreen forests are in general characterized by a low phytodiversity, whereas many of the cultural landscapes are species rich in plants (Naveh 1994). Today, successional shrub-dominated communities such as garrigue and maquis characterize the Mediterranean landscape. However, due to the natural ecological and geographical features as well as the influence of humans in the past centuries, the Mediterranean region is one of the world´s major centers of plant diversity, and especially rich in plant endemism (Myers et al. 2000; Naveh 2007). Of the 25,000 flowering plants identified so far and representing 10% of the world's plant species pool while covering only 1.6% of its surface area, about 50% are endemic to the region (Médail & Quézel 1997; Myers et al. 2000).

Besides land-use change, climate change is considered as an important trigger for the future development of flora and fauna in the Mediterranean region. Several studies already point to ongoing biotic changes due to climate change (Chelli et al. 2017). Giorgi (2006) identified the Mediterranean area as one of the two regions most affected by climate change on earth. Up until 2100, a rise in mean temperature between 0.3 - 4.8 °C is expected (IPCC 2014). Precipitation is expected to be reduced up to 40% in summer. Particularly in regions like NW Sardinia with several rain-free months and intense rainfall events, further changes in these extremes might have considerable degrading effects on vegetation and land use (Harding et al. 2009).

In many parts of the world, forest restoration has become a major goal to restore degraded landscapes (Zerbe 2002; Chazdon 2008; Stanturf 2015). Also in the Mediterranean area, forest restoration is of increasing interest and respective projects have been initiated (Gómez-Aparicio et al. 2004; Vallejo 2005; Puértolas et al. 2010; Chiatante et al. 2017). In comparison to the temperate region, forest restoration in the Mediterranean is often more difficult due to the warmer and drier climate, the likelihood of fire, but also due to high grazing pressure. As a result of the harsh environmental conditions of this region, reforestation undergoes high rates of plant mortality (Mesón & Montoya 1993). One main resource of stress is summer drought that limits the recruitment of both natural and planted seedlings (Rey & Alcántara 2000; Castro et al. 2002). In many restoration attempts, seedling mortality during the first summer drought presents the main problem (Maestre et al. 2001; Castro et al. 2004). Besides these environmental obstacles, grazing animals as well as wild boars pose a threat to tree regeneration and seedling survival (Gómez et al. 2008). Therefore, protection measures like fencing of reforestation areas have to be taken into account.

It is indisputable that for most restoration projects, increasing the forest area to restore the forest's ecosystem services represents the primary goal. As cultural landscapes and semi-natural habitats are often also valuable and important for biodiversity conservation (Naveh 2007) and provide particular ecosystem services, e.g. for tourism and groundwater recharge (Swinton et al. 2007; Schaich et al. 2010), restoration projects and nature conservation efforts should carefully balance the benefits of different habitat types for the eco-social development of a given region. To achieve this, a comparison of biodiversity levels and/or ecosystem services between the different habitat types is a suitable tool (Nelson et al. 2009; Fontana et al. 2013). This is even more important for restoration efforts and nature conservation in protected areas such as national parks, since here various protection goals (e.g., species conservation vs. naturalness, cultural landscape) often coexist. Unfortunately, few studies comparatively evaluate if forest restoration or the maintenance of cultural open habitats should be defined as a primary restoration goal. Accordingly, we aim to fill this knowledge gap.

For our study, we have chosen the island and

National Park of Asinara (NW Sardinia, Italy) as an example for the Mediterranean region as the island's landscape has been shaped over millennia by human activities. Today, only 0.7% of the area consists of evergreen forest; the rest is mostly dominated by secondary shrub vegetation and grassland. A high amount of grazing animals and wild boars keep the landscape open and make forest restoration attempts by the National Park challenging. The Park aims to enlarge forests on the one hand but also wants to sustain the current phytodiversity and cultural vegetation types. These circumstances reflect a situation, which is often found in the Mediterranean, in which Asinara is a suitable case study area to discuss the controversy over the maintenance of open cultural land and forest restoration. Since in the Mediterranean region plant diversity is especially high (Myers et al. 2000) our research focusses on phytodiversity as a key feature of overall high biodiversity and we incorporate the topsoil seed bank, as it has a fundamental impact on diversity on composition of the vegetation (Fenner & Thompson 2005). We address the following questions:

1. How do native forest and secondary vegetation differ regarding their diversity of vascular plants and top soil seed bank?
2. What forest restoration scenarios can be derived on the basis of the actual site conditions and with regard to the National Park's management plan, and
3. How should forest restoration be brought into practice?

## Material and methods

### *Study area*

The study was conducted on the Italian island of Asinara (51.9 km$^2$), located in the northwest of Sardinia (Figure 1). According to Rivas-Martínez et al. (2011), the bioclimate is classified as mediterranean-pluviseasonal-oceanic. Mean annual temperature is about 17.7 °C with highest temperatures in August and lowest in February. Mean annual precipitation reaches 430 mm, with a maximum rainfall between October and April (Osservatorio ambientale Parco Nazionale dell'Asinara, unpubl.). The bedrock consists mainly of metamorphic complexes (mica schist, paragneiss, orthogneiss and migmatites) and intrusive magmatic granite formations (Carosi et al. 2004). The soil geography is characterised by a mosaic of soil types with mainly lithic, cambic, umbric or mollic leptosols, leptic cambisols, and luvisols (Stadtmann, unpubl.).

Regarding the potential vegetation, the majority of the island´s landscape would be forest dominated by holm oak (*Quercus ilex* L.), Phoenicean juniper (*Juniperus phoenicea* L.) and wild olive formations (*Olea europea* L. *ssp. europea var. sylvestris*) (Bocchieri & Filigheddu 2008; Blasi 2010). While holm oak forest is supposed to dominate the higher elevations of the northern part of the island, olive formations would be distributed throughout the island and juniper forest formations would mainly occur in the central and southern part of Asinara (Figure 1).

For centuries the island of Asinara was used by shepherds before becoming a quarantine station and agricultural working prison in 1885. At this time, the island's landscape already consisted of 70 ha grazed land and only 45 ha of forest (Doneddu 2008). Thus, not only a constructed hypothetical forest vegetation can be identified but also forest remnants of relatively young cultural history. Later on, the island became a prisoner-of-war camp and high security prison. As a result, the landscape and vegetation were continually altered by human influence, through deforestation, farming, livestock breeding and deliberately set fires (Pisanu et al. 2014).

Asinara stayed a publicly prohibited area until becoming a National Park in 1997 and a site of community importance within the European Natura 2000 network of protected areas. After the prison closure, a large number of domestic ungulates was released allowing for their uncontrolled proliferation. Until 2007, they comprised 7,000 goats, 300 donkeys, and 180 horses. Furthermore, approx. 600 mouflons and 1,000 wild boars were present, which have been introduced for hunting before the designation as National Park. Until 2011, eradication measures reduced goats to 3,000 and wild boars to 300 animals (Pisanu et al. 2012). Based on recordings by Bocchieri (1988), Pisanu et al. (2014) and Drissen et al. (unpublished), 714 plant species and subspecies are known to occur on Asinara. 35 species are endemic to Sardinia and to other Western Mediterranean islands, respectively (Bocchieri & Filigheddu 2008). Today, the vegetation is dominated by secondary plant communities (Bocchieri & Filigheddu 2008; Drissen et al., unpublished).

### *Forest restoration activities and management goals of the National Park*

Information about former and present forest restoration activities on Asinara Island was given by staff members of the National Park and the forestry authority of Sardinia, as well as by the current management plan for the protected area. In 1995, prior to any reforestation measures, an area of 200 ha including the remain-

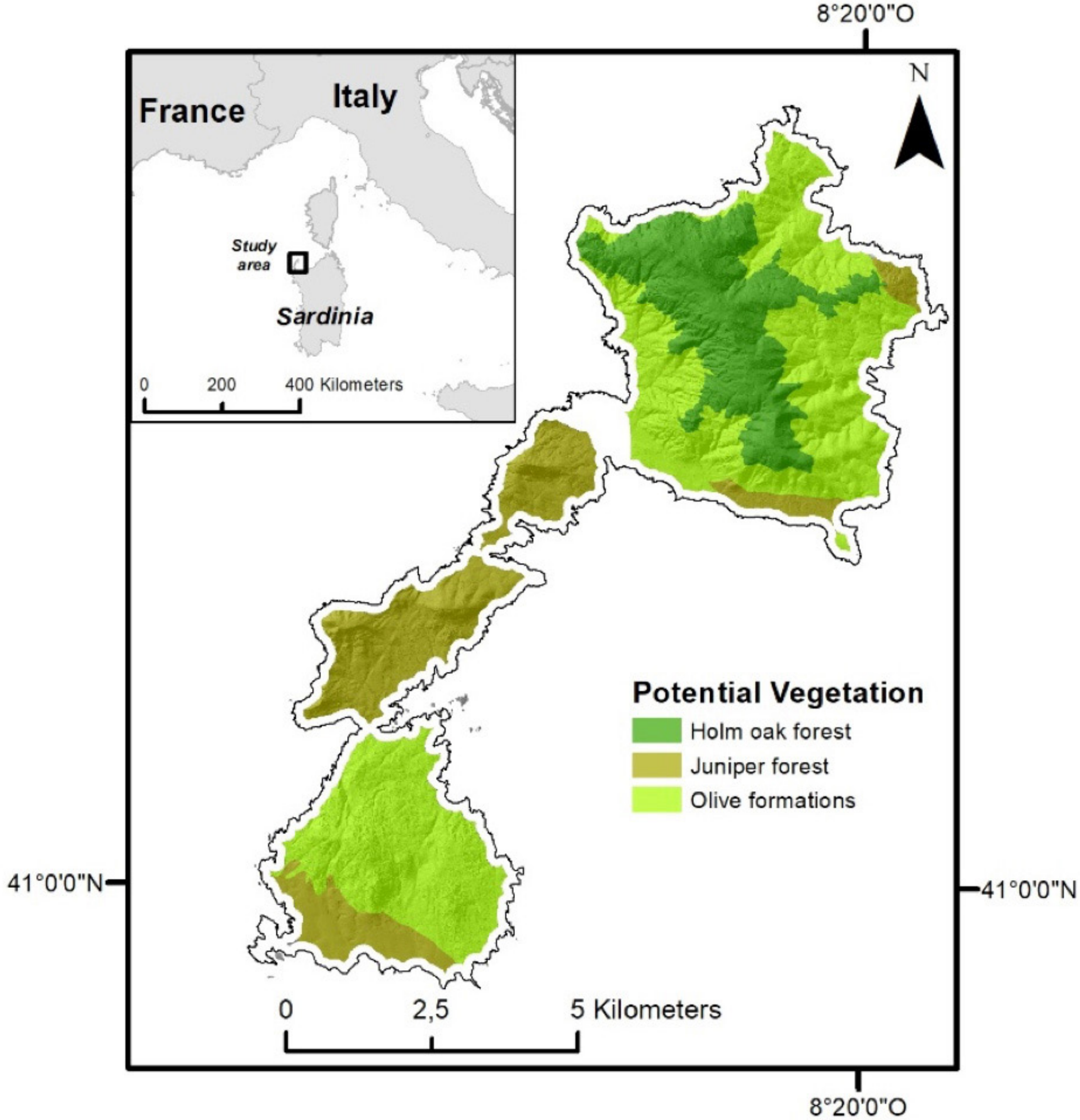


**Figure. 1:** The location of the island of Asinara in NW Sardinia and its potential natural vegetation according to Bocchieri & Filigheddu (2008, slightly modified).

ing holm oak forest in the northern part of the island was fenced to exclude feral ungulates, and therewith, mitigate their impact on oak development (Giannasi 2014, pers. comm.). In 1998, the restoration of the island's forest areas was initiated, focussing on the preservation and extension of holm oak (*Quercus ilex*) and Phoenician juniper (*Juniperus phoenicea*). Within the fenced area between 70,000 and 80,000 saplings (80% oaks) have been planted without artificial water supply (Careddu 2017, pers. comm.). Due to a lack of maintenance, the fencing is nowadays incomplete, allowing mainly goats and wild boars to enter the area. The increased occurrence of the oak processionary (*Thaumetopoea processionea*) during the last years poses another threat for the holm oak forest (Giannasi 2014, pers. comm.).

The current management plan includes the long-term objective of realizing natural forest vegetation on at least 30% of the island's surface. However, target areas, approach and time scale for reforestation are yet to be clearly defined. The management plan also specifies the gradual eradication of goats and wild boars to ensure reforestation success and forest development. Furthermore, population densities of mouflons, donkeys, and horses should be controlled (Bardi et al. 2015).

*Vegetation sampling*

To compare plant diversity and composition between the existing forest areas on the island and secondary habitats, we randomly selected 48 plots representing the following vegetation types (1) holm oak forest (potential natural vegetation, a small and fenced area is left in the north of the island, n = 5), (2) holm oak forest remnants (also in the northern part, without fencing, n = 3), (3) Phoenicean juniper forest (natural near the coastlines, n =10), (4) secondary maquis scrubland dominated by *Euphorbia dendroides* (n = 10), (5) secondary garrigue scrubland dominated by shrubs *of Cistus monspeliensis* (former land use type associated with fires for clearing of land, n = 10) and (6) secondary successional open grassland (grazed mainly by horses, n = 10). On all plots (each with a size of 100 $m^2$) vegetation surveys were conducted between March and May 2014 using a continuous percentage scale. Plots were visited again between July and August 2014 to record any late flowering species. Special attention was given to seedlings and saplings of tree species, namely *Quercus ilex* ssp. *ilex* and *Juniperus phoenicea* ssp. *turbinata* to evaluate the species' regeneration potential.

*Vegetation mapping*

To develop scenarios for forest restoration on Asinara Island, we used detailed information about the area covered by different vegetation types by means of a digital mapping performed by Stadtmann et al. (2016) who used remote sensing techniques and digital image analysis with the program ERDAS IMAGINE (Hexagon Geospatial, Madison, US, 2015). A pixel-based Supervised Classification via Maximum-Likelihood-Algorithm was conducted based on field data and high-resolution satellite pictures. By evaluating the results and integrating auxiliary geodata and visual interpretation of orthophotos in a geographic information system a high resolution vegetation mapping was accomplished.

*Soil seed bank analysis*

To assess soil seed bank properties, topsoil samples were collected at the end of May and the end of August 2014. On each plot of a subset of six plots per vegetation type, except for the holm oak forest with three plots, a total of ten samples (3 cm deep, 4 cm diameter), five in spring and five in late summer, were taken using a soil corer. As we were interested in the seeds already incorporated in the top soil, any litter was removed beforehand. Due to logistical reasons the holm oak forest remnants could not be sampled. The samples were air dried and stored at room temperature until use. Between December 2014 and July 2015 a greenhouse germination trial was performed using the seedling emergence method (Thompson et al. 1997). Soil samples were concentrated beforehand by washing through a fine sieve after the method of Ter Heerdt et al. (1996). Each sample was spread on planting trays over sterilized potting mix, placed in the greenhouse and watered every day. In the greenhouse mean temperature was 19.1 °C (range 11.7 – 35.6 °C) and mean relative humidity was 67% (range 25 - 94%). The day length of 10 h 22 min was adapted to the mean day length on the island during vegetation period. We used plant luminaries (high pressure sodium vapour lamp Sirius X400, Bio Green OHG, Bischoffen-Oberweidbach, Germany; 55000 Lumen at 1.3 m distance) with mean photosynthetically active radiation (PAR) values of 200 µmol $m^{-2}$ $s^{-1}$ (MQ-200, Apogee Instruments, Inc., Logan, Utah, USA). Trays were rotated weekly allowing for the same environmental conditions for all samples. To record any external seed input, control trays with sterilized potting mix were placed randomly. Germination was monitored on a daily basis. Seedlings were identified and removed or, if identification was not yet possible, transferred for further cultivation.

*Statistical analyses and diversity measures*

Floristic diversity of each vegetation type concerning vegetation surveys and seedling emergence trial was evaluated by means of alpha diversity (Whittaker 1972) and Simpson's diversity index (Simpson 1949). Simpson's index as heterogeneity measure performs well even at smaller sample sizes (Magurran 2004). To evaluate if alpha diversity differs significantly between vegetation types, a one-way ANOVA was performed using SPSS Statistics 24 (IBM Corp., Armonk, US). Equal variances (Levene's test) gave reason for a post-hoc Tukey HSD test ($p \leq 0.05$). In case of unequal variances, a post-hoc Games-Howell analysis ($p \leq 0.05$) was conducted. Concerning Simpson's diversity index, the non-parametric Kruskal-Wallis test ($p \leq 0.05$) followed by multiple pairwise Mann-Whitney U tests ($p \leq 0.05$) were conducted. To avoid the inflation of the alpha error, Holm's sequential Bonferroni procedure was implemented afterwards.

## Results

*Plant diversity of forests and secondary habitats*

On the 48 plots, a total of 322 plant species could be recorded. Highest mean species richness (alpha diversity) was found in the *Cistus* garrigue (73.1 ± 3.2 species) and the maquis scrubland (68.8 ± 5.3) while the lowest was found in the holm oak forest (34.0 ± 3.0) and forest remnants (32.0 ± 7.5) (Figure 2). While only one species was limited to the non-fenced holm oak forest remnants, 10 species were restricted to the fenced holm oak forest area. The open or half-open vegetation types contained a larger number of plant species with exclusive occurrence, i.e. 28 species for the open grassland, 22 species for the *Cistus* garrigue, and 11 for the maquis. However, for the Juniper forest formations 27 exclusive species could be recorded. As far as Simpson's diversity index is concerned, we found highest values in the open grassland (0.88 ± 0.02), maquis scrubland (0.86 ± 0.02) and *Cistus* garrigue (0.83 ± 0.02) (Table 1). The oak forest showed significantly lower values (0.48 ± 0.08).

**Table 1:** Simpson's diversity index of vegetation and seedling emergence trial calculated for the different vegetation types; given are mean values with standard errors. Significant differences ($p \leq 0.05$) are marked by different lowercase letters. Number of plots (n) is indicated.

| | Vegetation | | Seedling emergence | |
|---|---|---|---|---|
| | **N** | **Simpson's index** | **N** | **Simpson's index** |
| Oak forest | 5 | 0.48 (± 0.08)$^{a}$ | 3 | 0.73 (± 0.01)$^{a}$ |
| Oak forest remnants | 3 | 0.30 (± 0.11)$^{ac}$ | - | - |
| Juniper forest | 10 | 0.73 (± 0.05)$^{ab}$ | 6 | 0.85 (± 0.03)$^{a}$ |
| Maquis | 10 | 0.86 (± 0.02)$^{bc}$ | 6 | 0.89 (± 0.02)$^{a}$ |
| Garrigue | 10 | 0.83 (± 0.02)$^{bc}$ | 6 | 0.89 (± 0.02)$^{a}$ |
| Grassland | 10 | 0.88 (± 0.02)$^{c}$ | 6 | 0.78 (± 0.03)$^{a}$ |

Regarding abundance and recruitment of holm oak (*Quercus ilex*) and Phoenician juniper (*Juniperus phoenicea*), Table 2 shows the occurrence of these tree species in the vegetation types divided into different vegetation layers. Holm oak occurred almost exclusively in the oak forest and oak forest remnants. Only one specimen was recorded elsewhere, in the herb layer of the juniper forest. Within the oak forest and oak forest remnants, the holm oak forms a dense tree layer. However, only a small percentage was found in the herb layer while almost no specimens were found in the shrub layer of the corresponding plots. This indicates a low natural recruitment of holm oak and a lack of young-growth stands. Phoenician juniper was exclusively found in the juniper forest type, mainly constituting the tree layer, but also occurring as recruitment in the herb and shrub layer of this vegetation type.

*Actual distribution of forests and forest remnants*

The digital mapping of the actual vegetation on Asinara Island shows that potential natural vegetation types are rare. Holm oak forest covers only 0.4% (20.3 ha) of the island's surface and is only found in the north of the island (Figure 4). Most of this forest is restricted to one area that has been fenced by the National Park to exclude grazing animals and wild boars. However, the fence is not well maintained, allowing mainly goats and wild boars to enter the area. Besides the fenced forest area, some small holm oak forest remnants are present in the northern part of the island. On Asinara juniper forest formations are rare, too, only covering an area of 0.3% (17.1 ha). Today, Phoenician juniper is mainly distributed along the coastlines. Both vegetation types are categorized as habitats of community interest within the European Habitats Directive and measures for their conservation and development are therefore legally required. Today, wild olive trees are rarely present on Asinara. Instead

**Table 2.** Mean cover values with standard errors of tree species in the vegetation layers of the studied forest vegetation types. Non-forest vegetation types are not shown as no tree species were recorded there. Number of plots in the oak forest = 5; oak forest remnants = 3; juniper forest= 10.

| Recorded tree species | Vegetation layer | Unit | Vegetation type | | |
|---|---|---|---|---|---|
| | | | **Oak forest** | **Oak forest remnants** | **Juniper forest** |
| *Quercus ilex* | Tree | % | 78.0 (± 2.8) | 90.7 (± 0.9) | 0 |
| | Shrub | % | 0.4 (± 0.2) | 0 | 0 |
| | Herb | % | 1.0 (± 0.3) | 0.2 (± 0.1) | 0.01 (± 0.01) |
| *Juniperus phoenicea* | Tree | % | 0 | 0 | 40.0 (± 10.2) |
| | Shrub | % | 0 | 0 | 14.6 (± 3.8) |
| | Herb | % | 0 | 0 | 3.5 (± 1.9) |

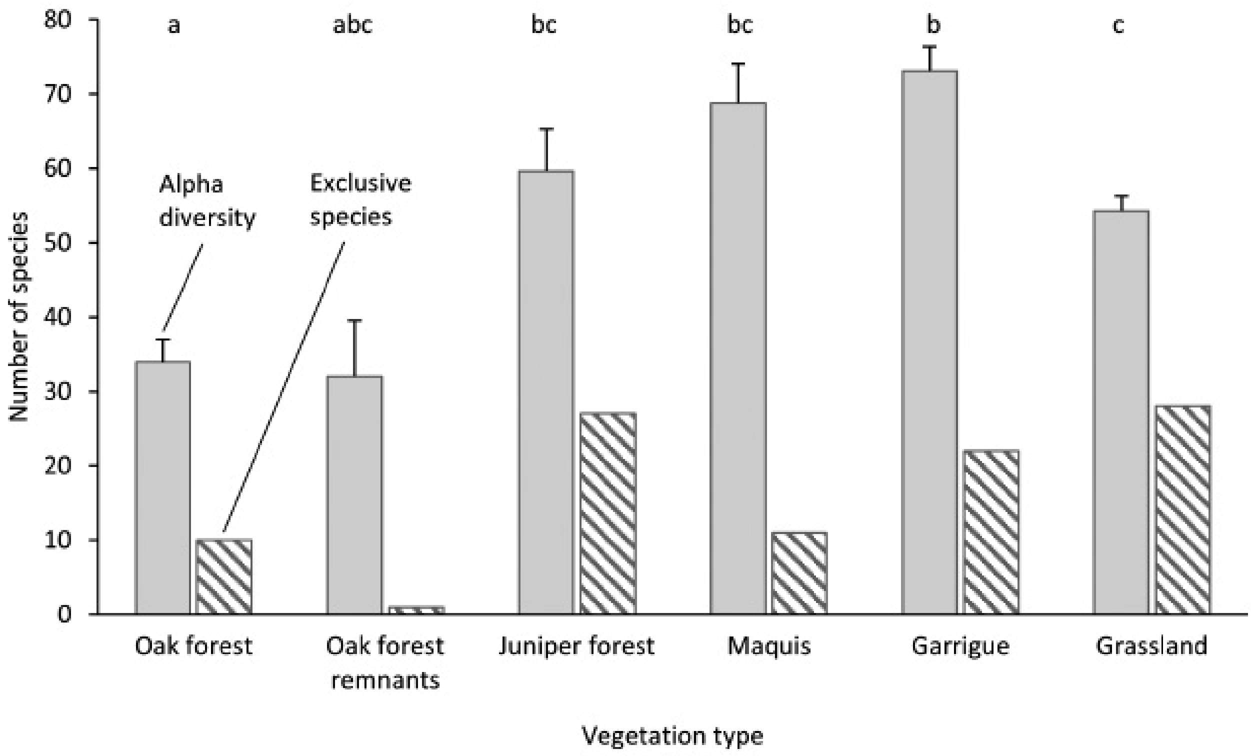


**Figure. 2:** Alpha diversity recorded in the different vegetation types; given are mean values with standard errors. Significant differences ($p \leq 0.05$) are marked by different lowercase letters. Additionally, absolute numbers of plant species exclusively occurring in each type are presented. Number of plots in the oak forest = 5; oak forest remnants = 3; juniper forest= 10; maquis = 10; garrigue = 10; grassland = 10.

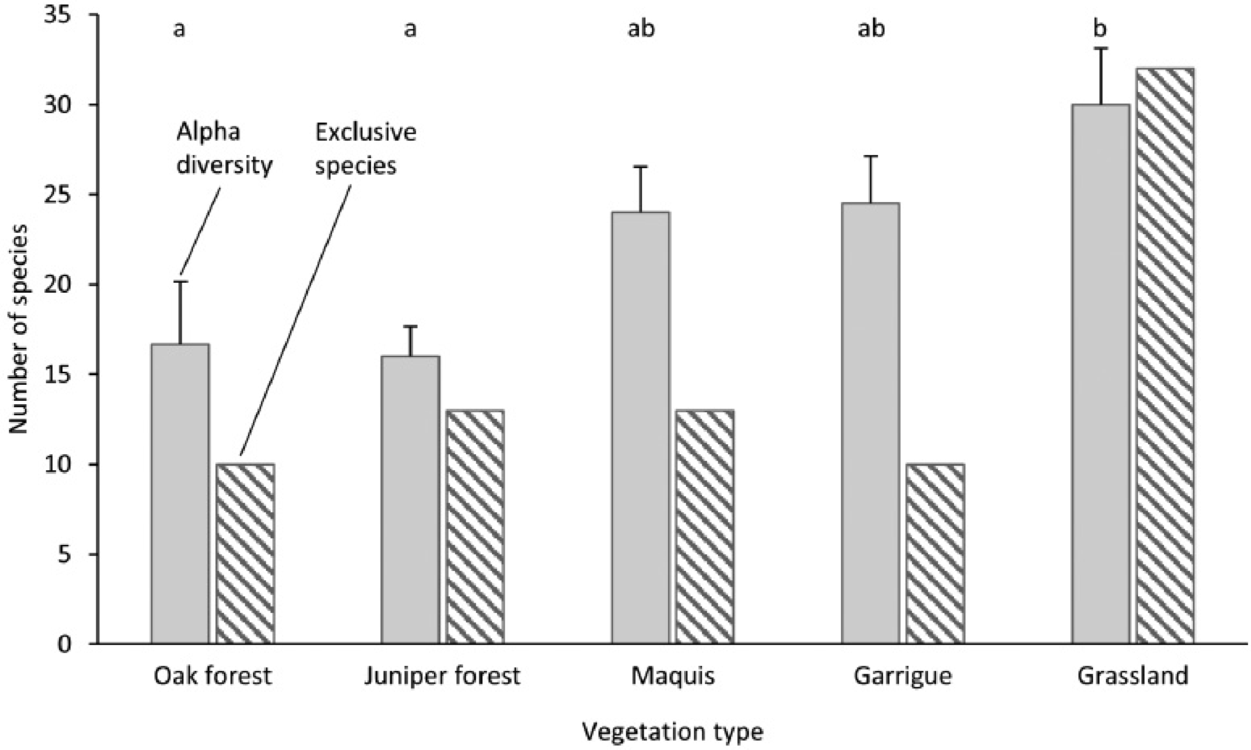


**Figure. 3:** Alpha diversity recorded in the seedling emergence trial for the different vegetation types; given are mean values with standard errors. Significant differences ($p \leq 0.05$) are marked by different lowercase letters. Additionally, absolute numbers of plant species exclusively germinated in each type are presented. Number of plots in the oak forest = 3; juniper forest= 6; maquis = 6; garrigue = 6; grassland = 6.

the cultivar of olive trees is found in valleys (0.3%, 17.1 ha). Most of Asinaras surface is today dominated by open or half open (scrubland) vegetation types. The largest part of Asinara is covered by maquis (26.8%, 1372.9 ha) followed by the *Cistus* garrigue (23.4%, 1195.8 ha). Furthermore, grasslands (18.6%, 950.7 ha) and coastal vegetation types (11.7%, 594.6 ha) are common (Stadtmann et al. 2016).

*Soil seed bank*

During the germination trial, a total of 5,099 seedlings belonging to 153 plant species emerged. Referring to alpha diversity, a significantly higher mean number of plant species emerged in the open grassland samples (30.0 ± 3.1), compared to the juniper forest (16.0 ± 1.7) and holm oak forest (16.7 ± 3.5) samples (Figure 3). Furthermore, the grassland samples showed the highest number of exclusive plant species. Simpson's diversity was highest in the maquis scrubland (0.89 ± 0.02) and *Cistus* garrigue (0.89 ± 0.02) and lowest in the oak forest (0.73 ± 0.01), however, no significant differences could be revealed (Table 1).

## Discussion

*Maintaining open cultural landscape or restoring forest ecosystems?*

Mediterranean forest ecosystems provide various ecosystem services, including an overall high biodiversity (Palahi et al. 2008). However, land use over millennia has largely altered the Mediterranean region into a cultural landscape that is dominated by secondary shrub vegetation (Naveh 2007; Nocentini & Coll 2013). The transformation from undisturbed environments to extensively used cultural landscapes generally enriches phytodiversity (Dierschke 1994) whereas evergreen forests are known to be less species rich (Naveh 1994). This is confirmed by our study as we found a mean of only 34 plant species in the holm oak forest compared to a mean of 65 plant species in the secondary vegetation types. Accordingly, Simpson's diversity index reached significantly higher values in the grassland and scrubland vegetation compared to the forest sites. Also, many endemic Mediterranean plant species have their main occurrences in open landscapes (Ojeda et al. 1995; Pignatti & Pignatti 1999). Although Asinara has a high phytodiversity of 714 plant species on only 52 km$^2$ (Bocchieri 1988; Pisanu et al. 2014), vascular plants are often key indicators for overall species' richness and do often not correlate with the number of animal species. Instead, the number of animal species often correlates with increasing structural complexity and vegetation height (Hambler & Canney 2013). Several studies highlight the difficulty to restore forest ecosystems in the Mediterranean region as natural regeneration is often low and environmental conditions are harsh (e.g. Mesón & Montoya 1993; Maestre et al. 2001; Castro et al. 2002). Therefore, the question arises why forest restoration should be a primary goal for nature and biodiversity conservation in the Mediterranean region.

Today natural forest ecosystems cover only an area of 9.4% in the Mediterranean region (Arianoutsou et al. 2012) and only 0.7% on Asinara Island (including holm oak and juniper). Myers et al. (2000) and Médail & Myers (2004) assume that less than 5% of today's vegetation can be regarded as primary vegetation. This is why Mediterranean evergreen forests are protected within the European Habitats Directive and identified as one of the most valuable and endangered ecosystems (Giordano 2013). Consequently, enlarging the forest area has to be one of the crucial tasks and challenges of sustainable landscape development in the Mediterranean region. Forest ecosystems provide several important ecosystem services that half-open and open habitats do not offer (or just at lower levels). They play, for instance, an important role concerning the global carbon cycle as they, sustainably managed, act as carbon sinks (Harrison et al. 2010; Pan et al. 2011). They also make a key contribution to erosion regulation and the prevention of desertification (Blondel & Aronson 1999; Harrison et al. 2010) which is of particular importance in the Mediterranean region where soil development is very slow. Mature forests with a variety of micro-habitats are of great importance for saproxylic insects, spiders, birds, and bats (Grove & Rackham 2001; Regenery et al. 2013; Tab. 3). Out of 366 known bird species in the Mediterranean region, 144 are characteristic for forest vegetation. Several bat species depend on forests for foraging and roosting (Barclay et al. 1996; Meschede & Heller 2000; Lacki et al. 2007). For Asinara Island, at least 10 bat species are reported by Winter et al. (2017), of which most are known to be forest dependent. The small forest area on Asinara might therefore serve as a last refugium for bats. In addition, forests are also important regarding bryophytes, lichens, and fungi (Chiarucci et al. 2007; Bässler et al. 2012; Hambler & Canney 2013). On Asinara, 43 out of 74 bryophyte species are restricted to holm oak habitats and a total of 17 species occurred exclusively within this vegetation type (Cogoni et al. 2009).

In terms of biodiversity, for numerous taxa half-open and open semi-natural habitats have a higher importance than forests (Moreira & Russo 2007; Sirami et al. 2010). This is especially the case for the Mediterranean region where several species have adapted to the high rate of both natural (e.g. fire) and human disturbances (e.g. agriculture, grazing animals). The high phytodiversity of the open and semi-open vegetation types, as well as the numerous exclusive plant species found in this study indicate this adaption. For birds it has been reported that typical Mediterranean species occur predominantly in grassland or open shrub land (Sirami et al. 2010). Also reptiles prefer open semi-natural habitats whereas amphibians are more restricted to forest vegetation (Sirami et al. 2010). Especially endemic species and species with a high conservation value are more dominant in semi-natural habitats than in forests (Blondel & Aronson 1999; Caplat et al. 2006).

However, the most important aspect for biodiversity conservation in the Mediterranean region is the maintenance of high landscape heterogeneity (Atauri & de Lucio 2001). The distinctive mosaic of the Mediterranean landscape, which is the result of topographic and climatic variabilities coped with the influence of natural and human disturbances, makes the region to one of the world's biodiversity hotspots (Myers et al. 2000).

*Forest restoration scenarios and limitations*

After Bocchieri & Filigheddu (2008), the potential natural vegetation of Asinara would be dominated by three major units which all represent forest vegetation. Due to land-use practices and high grazing pressure, forest vegetation is currently limited to 0.7% of the island's surface. As throughout Europe grazing and browsing pressure, respectively, is one of the crucial limitations for natural reforestation and forest restoration the management of animals or the exclosure of those represents one of the major tasks.

Stadtmann (2013) identified an expansion of the shrubby vegetation in the northern part of Asinara dating back to the middle of the last century. The remaining forest areas can therefore be regarded as an appropriate indicator for passive forest restoration on Asinara. Since the holm oak has a wide ecological adaptability (Camarda 2003), restoration activities for this species on Asinara should focus on minimizing the isolation of forest fragments and the remaining forest at the northern part of the island with regard to their reduced areas and floral changes into a more coherent whole (Biringer & Hansen 2005; Zerbe 2009; Hambler & Canney 2013). Due to the low natural regeneration of oak and juniper recorded in this study, planting of seedlings or saplings should be preferred.

According to the results of the digital vegetation mapping, environmental circumstances and the forest restoration goals of the National Park, we illustrate three scenarios (Figure 4), which are set as short- and long-term objectives:

**Scenario 1:** As a short-term objective, the holm oak forest area should be increased by planting from currently 20 ha to approximately 200 ha, comprising the already fenced area in the northern part. This is in accordance with the ongoing reforestation measures of the National Park. However, we strongly suggest renewing and maintaining the fence so that grazing animals and wild boars are completely excluded. In

**Table 3:** Biodiversity as an ecosystem service of forests compared to secondary habitats such as scrubland and grassland; assumptions are made on the basis of literature and expert knowledge, differentiating * = low to *** = high significance.

| | Forest | Scrubland | Grassland | Authors |
|---|---|---|---|---|
| Vascular plants | * | *** | ** | This study, Naveh 1994, Naveh & Wittaker 1979, Chiarucci et al. 2007, Chitý et al. 2010, Amici et al. 2013 |
| Top soil seedbank | * | ** | ** | This study, Parker & Kelly 1989, Fenner & Thompson 2005 |
| Bryophytes | *** | * | - | Chiarucci et al. 2007, Cogoni et al. 2009, Brunialti et al. 2010 |
| Lichens | *** | ** | * | Esseen & Renhorn 1998, Belichón et al. 2007, Hambler & Canney 2013 |
| Fungi | *** | * | - | Richard et al. 2004, Bässler et al., 2012 |
| Saproxylic insects | *** | * | | Buse et al. 2010, Micó et al. 2013, Ramírez-Hernández et al. 2014 |
| Amphibians | *** | * | * | Gibbs 1998, Hambler & Canney 2013 |
| Reptiles | * | *** | ** | Fuentes 1981, Carrascal et al. 1989, Sirami et al. 2010 |
| Birds | ** | ** | * | Rocamora et al. 1997, Blondel & Aronson 1999, Blondel & Médail 2009, Bengtsson et al. 2000, Sirami et al. 2010 |
| Bats | *** | * | * | Russo et al., 2004, 2010, Barclay et al. 1996; Meschede & Heller 2000; Lacki et al. 2007 |
| Wildlife habitat | *** | ** | * | Grove & Rackham 2001, Palahi et al. 2008, Regenery et al. 2013 |

addition, we recommend to enlarge the areas covered by juniper forest formations in the central part of the island from 17 ha to approximately 80 ha. Despite the lower palatability of the Phoenician juniper, fencing is strongly suggested, too, to prevent saplings from trampling and churning by feral ungulates.

**Scenario 2:** For a medium-term objective, we suggest connecting the fenced holm oak forest area with the existing holm oak fragments through corridors or stepping stones, comprising an area of 400-450 ha. For this scenario, we propose to focus on the eastern slopes of northern Asinara to avoid the harsh climatic conditions due to the predominantly northwestern winds in this region (Donda et al. 2008). According to Graen et al. (2015) the highest altitudes of Asinara show the highest temperatures in very hot periods. To connect the existing fenced holm oak forest area with the remnants, we thus propose to focus on the lower altitude valleys for reforestation measures, since they provide better microclimatic conditions, mitigating the resulting water stress. Furthermore, soils are deeper at the foot- and toe slopes and soil moisture availability is higher. To avoid detrimental influence by grazing animals and wild boars, we suggest fencing all reforested areas. As part of this scenario, we further suggest to increase the fenced juniper forest areas in the central part of the island up to 200 ha.

**Scenario 3:** In the long term, we suggest to expand the holm oak forest area to approximately 600 ha and the juniper forest area to approximately 300 ha, considering suitable topographic conditions. For this scenario, we recommend to completely exclude goats and wild boars from the northern part of the island by establishing a fence, e.g. at an isthmus, combined with eradication efforts within the fenced area. In the southern part of Asinara it would be possible to establish Juniper forest also on granite formations, which Bocchieri & Filigheddu (2008) list as a separate potential vegetation type. Following this scenario nearly 20% of the island's surface would be covered with forest vegetation. Although the National Park's objective of more than 30% forest area would be still distant, this scenario is more reasonable and based on our suggestions the restored areas of holm oak forest and juniper forest formations should have the possibility to develop natural dynamics and be able to rejuvenate and sustain themselves over the long term.

For Asinara and the whole Mediterranean region,

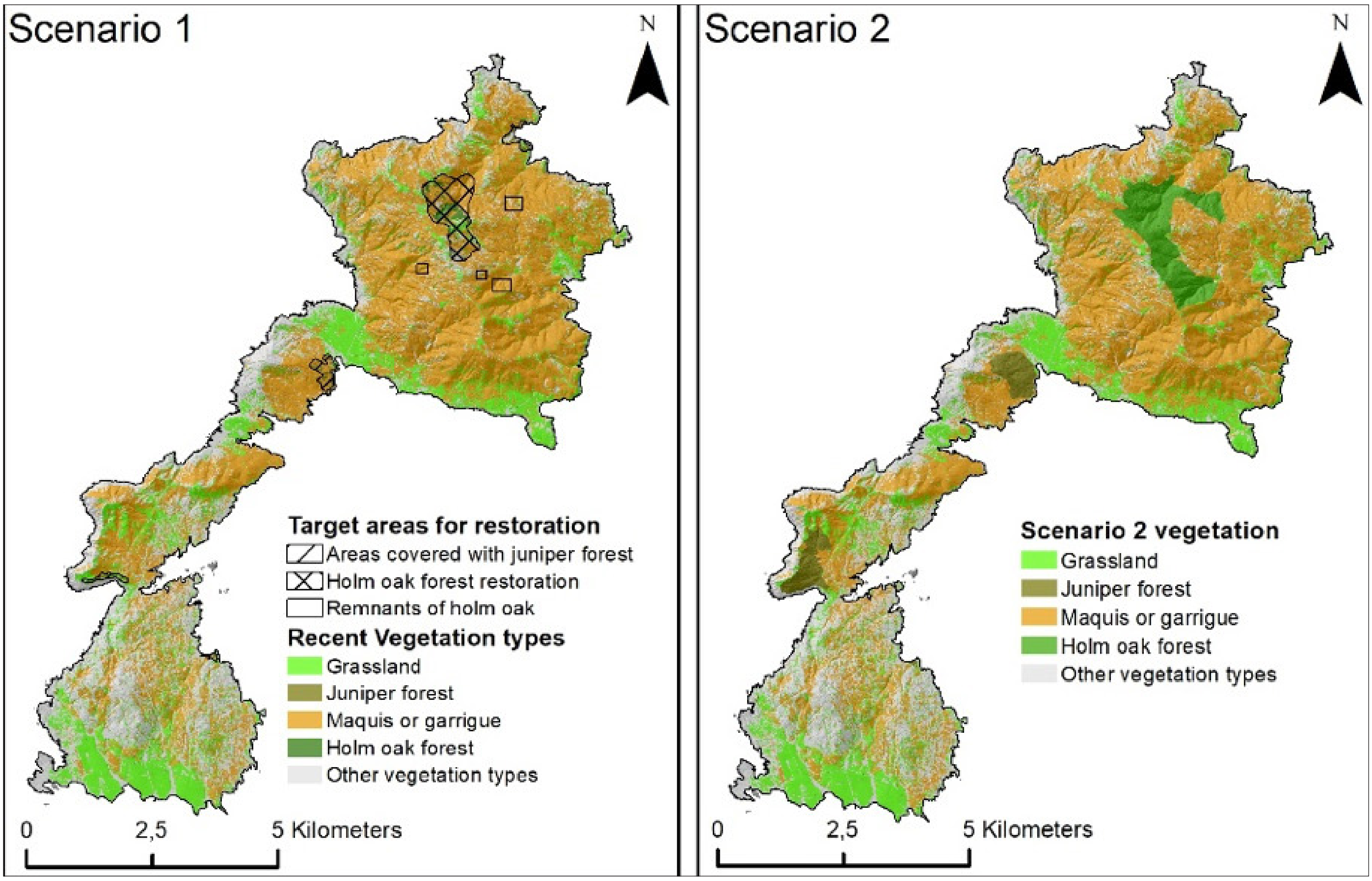


**Fig. 4a:** Different forest restoration scenarios for the island of Asinara (Scenario 1 and 2).

climate conditions and grazing influence are the two main factors which hinder natural tree regeneration and forest restoration. The Mediterranean is characterized by harsh climate conditions, including high temperatures, long summer droughts and fires. Many studies highlight that especially the first dry season is most critical for the survival of tree seedlings and saplings (e.g. Benayas 1998; Smit et al. 2009). Within the process of tree species regeneration the phase of seedling establishment is of particular importance because young seedlings are more vulnerable to stress factors, such as low or high irradiance, water shortage, which, in the long term determine community structure and composition (Zerbe 2002) and species distribution in the landscape (Niinemets & Valladares 2006). In our study, we only found a small number of holm oak saplings inside the forest and almost no oak saplings in other vegetation units. This can mainly be attributed to the low dispersal ability of Mediterranean oak species (Pausas et al. 2004) and might also be a result of the acorn's sensitiveness to dehydration and heat. Similarly, Gómez & Hódar (2008) and Farris & Filigheddu (2011) reported almost no seedling survival in open habitats due to drought effects. For successful reforestation through plantation of saplings, water availability should be increased, e.g. through the creation of small runoff collection areas next to the planting holes (Pausas et al. 2004). Additionally, irrigation during the first summer after planting should be considered (Benayas 1998). Another option to mitigate drought stress for saplings is the installation of artificial shading which reduces soil water evaporation and thus increases soil moisture (Pausas et al. 2004; Benayas et al. 2005).

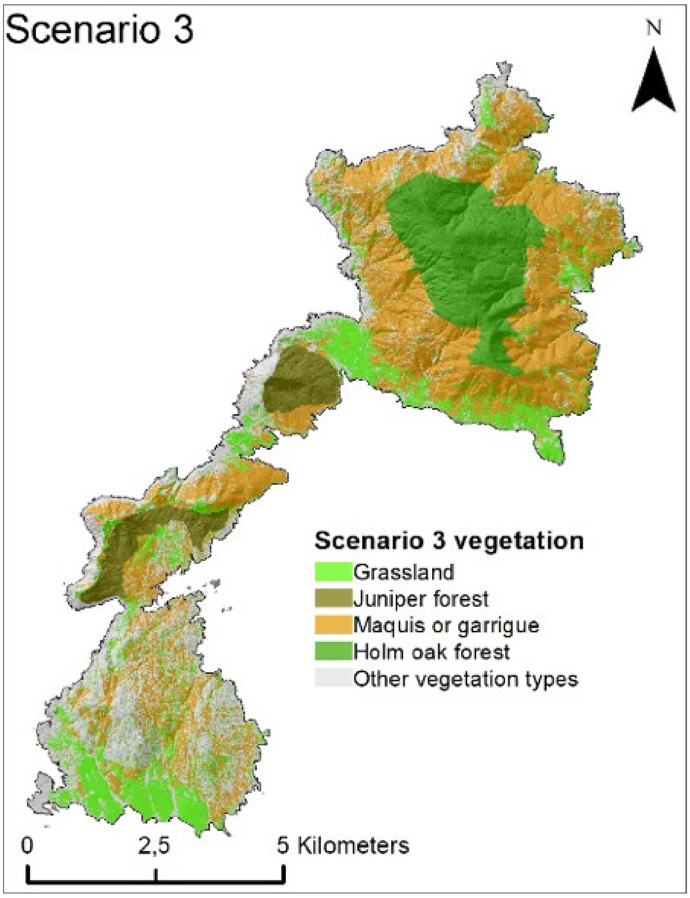


**Fig. 4b:** Different forest restoration scenarios for the island of Asinara (Scenario 3).

In the case of holm oak, active reforestation with seedlings or acorns is expensive and in summer often a failure due to the stressful conditions. If acorns are used, they should be rehydrated for 24 hours immediately before seeding (Catry et al. 2012). For active management nursery-grown saplings of local species, maybe combined with seeds, should be used to reintroduce target tree species (Pausas et al. 2004). To face climate change, individuals from areas with the projected future climates might be used as well (Hambler & Canney 2013).

Besides the harsh environmental conditions, many regions in the Mediterranean suffer from high amounts of grazing animals and wild boars. Our data indicate that the widespread feral ungulates on Asinara are a severe factor that prevents a rejuvenation of the holm oak forest. Predation is known to be a significant problem for regeneration of oak species (Crow 1988) and holm oak is supposed to be more sensitive to browsing than other Mediterranean plant species (Grove & Rackham 2001). Siscart et al. (1999) identified wild boars as one of the main species feeding on oak acorns. They also kill saplings while searching for acorns and fungi (Gómez & Hódar 2008). Goats which feed directly on oak leaves and young twigs play also an important role concerning forest regeneration (Terradas 1999). Accordingly, goats and wild boars are the feral herbivorous animals with the biggest influence on the landscape of Asinara Island (Falqui & Viridis 2008). Therefore, a cessation of grazing would give the vegetation the opportunity to recover, grow into trees and protect the land from erosion (Allen 2001). To enable this process, populations of goats and wild boars need to be substantially reduced and controlled, as they brought major changes in the structure and tree cover of many areas (Whittaker & Fernándes-Palacios 2007). However, the establishment of seedlings in most plant communities with a closed canopy requires some disturbance (Fenner & Thompson 2005). Thus, a moderate grazing regime, mainly by donkeys, horses and mouflons, with grazing-excluded patches for sensitive vegetation types should be aspired (Drissen et al., unpubl.). To reduce grazing on reforestation sites on

Asinara, ungulates should be excluded permanently or temporarily by (electric) fencing, which is the cheapest method for large areas with a high tree density (Nessing & Zerbe 2002; Catry et al. 2012; Hambler & Canney 2013). Individual plants could be protected with protective cylindrical-shaped wire mesh shelters which should be sufficiently strong and inelastic (Catry et al. 2012). Regarding the development of natural forest dynamics, it must be recognised, that it can take several years for woody species to establish a functioning seed bank for regeneration (Parker & Kelly 1989) and according to Saïd (2001), the establishment of a mature forest will take about 60 years after the end of grazing. It might be difficult to establish a larger forest area on Asinara but it is worth putting efforts into this to achieve this goal in the future.

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