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Ecological restoration across the Mediterranean Basin as viewed by practitioners

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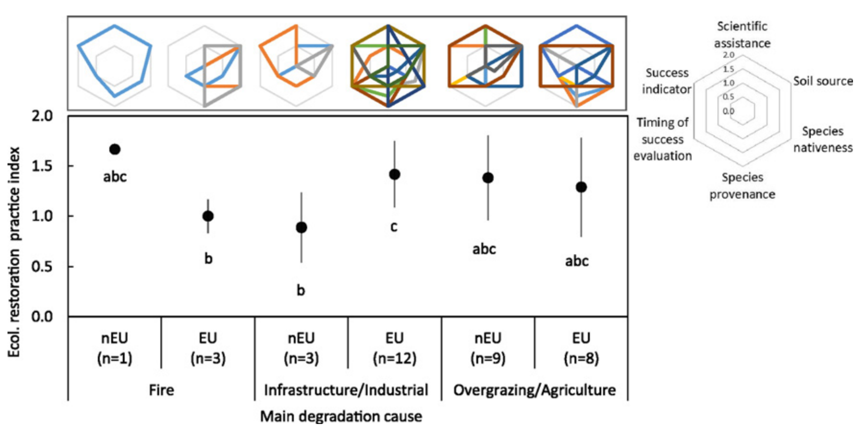
HIGHLIGHTS

- The degree to which projects follow ecological restoration principles is unclear.
- A survey was addressed to a wide range of practitioners in the Mediterranean Basin.
- An *ecological restoration practice index* revealed high variability among practices.
- More scientific assistance and use of native species of local provenance are needed.
- Long-term monitoring based on ecosystems' functions and services should be promoted.

GRAPHICAL ABSTRACT



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ABSTRACT

Restoration efforts in the Mediterranean Basin have been changing from a silvicultural to an ecological restoration approach. Yet, to what extent the projects are guided by ecological restoration principles remains largely unknown. To analyse this issue, we built an on-line survey addressed to restoration practitioners.

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We analysed 36 restoration projects, mostly from drylands (86%). The projects used mainly soil from local sources. The need to comply with legislation was more important as a restoration motive for European Union (EU) than for non-EU countries, while public opinion and health had a greater importance in the latter. Non-EU countries relied more on non-native plant species than EU countries, thus deviating from ecological restoration guidelines. Nursery-grown plants used were mostly of local or regional provenance, whilst seeds were mostly of national provenance. Unexpected restoration results (e.g. inadequate biodiversity) were reported for 50% of the projects and restoration success was never evaluated in 22%. Long term evaluation (>6 years) was only performed in 31% of cases, and based primarily on plant diversity and cover. The use of non-native species and species of exogenous provenances may: i) entail the loss of local genetic and functional trait diversity, critical to cope with drought, particularly under the predicted climate change scenarios, and ii) lead to unexpected competition with native species and/or negatively impact local biotic interactions. Absent or inappropriate monitoring may prevent the understanding of restoration trajectories, precluding adaptive management strategies, often crucial to create functional ecosystems able to provide ecosystem services. The overview of ecological restoration projects in the Mediterranean Basin revealed high variability among practices and highlighted the need for improved scientific assistance and information exchange, greater use of native species of local provenance, and more long-term monitoring and evaluation, including functional and ecosystem services' indicators, to improve and spread the practice of ecological restoration.

1. Introduction

The Mediterranean Basin has a long history of human activity which, coupled with its typical climatic regime of cool wet winters and hot dry summers, resulted in plant adaptations to clearing, grazing, fires, and drought (Davis et al., 1996). However, the intensification in land use (e.g. agriculture and grazing), the increase in fire frequencies, as well as urban development (e.g. infrastructure building), led to extensive areas of degraded lands exhibiting low biological productivity and slow ecosystem recovery rates after disturbances or abandonment of land use (Le Houerou, 2000; Zdruli, 2014). High water stress together with more intense and/or frequent disturbances often reduce ecosystem resilience, generating a positive feedback which exacerbates land degradation.

Most of the Mediterranean Basin territory, about 67%, is occupied by drylands (White and Nackoney, 2003). These water limited areas are classified according to the UNEP aridity index (0.05 < AI < 0.65) (Middleton and Thomas, 1992), and comprise from a higher to a lower aridity level, hyper-arid, arid, semi-arid, and dry sub-humid areas. Drylands are particularly vulnerable to desertification and land degradation (MEA, 2005; Maestre et al., 2012; Reynolds et al., 2007b), which affect the ability of the ecosystems to deliver ecosystem services, compromising people's livelihood and well-being (MEA, 2005; Reynolds et al., 2007a). Land degradation may be further aggravated by climate change, that is expected to generate warmer and drier conditions and a higher frequency of extreme events (heat waves, droughts and floods), which are expected to severely impact the Mediterranean Basin (MEA, 2005; IPCC, 2007).

In severely degraded areas with low resilience, restoration is the main means to reverse land degradation, and to restore ecosystems' composition, functioning and sustainability (SER, 2004), thus contributing to improve the welfare of local populations (Suding et al., 2015; Zucca et al., 2013). However, restoration actions are particularly challenging under the stressful conditions found in Mediterranean drylands (Cortina et al., 2011; Vallejo et al., 2012).

During the first half of the 20th century, many large restoration projects were conducted across the Mediterranean Basin. Initially, most of them relied on a silvicultural approach, with the introduction of a few fast-growing tree species, and intended to combine forest productivity with hydrological watershed protection, as well as to promote employment in remote rural areas. Hence, despite their contribution to reduce erosion and increase plant cover and productivity, in most cases they led to long-lasting mono-specific tree stands with low diversity (e.g. Cortina et al., 2011). As such, they could not be considered 'ecological restoration' in the strictest sense (Vallejo, 2009), at least without further management to promote biodiversity, particularly native species. According to the Society for Ecological Restoration (SER), ecological restoration must fulfill clearly stated goals for the target ecosystem: it should become similar to a non-disturbed or 'reference' ecosystem regarding: (i) species diversity, (ii) community structure, (iii) presence of functional groups and of native species, (iv) establishment of biotic fluxes with surrounding areas, (v) self-sustainability, and (vi) resilience to disturbance (SER, 2004; Suding et al., 2015). Moreover, it advocates the integration of scientific and other forms of knowledge into restoration practice, as well as the evaluation of restoration projects outcomes to assess whether the defined objectives are being achieved (SER, 2004). The restoration practice most commonly implemented in the Mediterranean region during the first half of the last century has been progressively replaced by a more ecosystem-based approach, with diversification of plant species, and due consideration given to both soils and fauna preservation. Recent legislation initiatives and environmental policies also played a role in changing the restoration paradigm, particularly in the European Union (EU). Ecological restoration became an essential target of EU vision and strategy for biodiversity, as illustrated by the habitat directive 92/43/EEC and the Convention on Biological Diversity, highlighting the importance of restoring and preserving local biodiversity. This shift in restoration practice has been reported in the Iberian Peninsula (Cortina et al., 2011; Oliveira et al., 2014), but to what extent it has spread to all the Mediterranean Basin remains largely unknown.

Recently, several important efforts have been made to gather information about restoration projects and to make it available, either as shared databases (e.g. REACTION project) or through meta-analysis of published papers (Aronson et al., 2010; Piñeiro et al., 2013). However, such information is often restricted to a region (e.g. the Northern Mediterranean, as in the case of the REACTION project) or the information is likely biased towards 'positive' restoration results. Furthermore, they do not reflect the full range of experience and technical knowledge held by practitioners. Therefore, despite the availability of several published works providing important theoretical reflections and guidelines for dryland restoration (Bainbridge, 2012; Bautista et al., 2009; Vallejo et al., 2012), a comprehensive report and diagnosis of the actual situation from the viewpoint of practitioners could be extremely useful to address a wide range of questions, such as: Does ecological restoration practice integrate scientific knowledge? Are native species being used in restoration projects? Are restoration outcomes evaluated, how, and for how long? Are results as good as expected? Answers to such questions are vital to assess the current ecological restoration efforts and to improve their efficiency and effectiveness in drylands and, particularly, in Mediterranean areas.

The general aim of this work was to understand whether ecological restoration projects implemented across the Mediterranean Basin follow ecological restoration stated goals, according to SER (SER, 2004).

We built an on-line open survey directed towards practitioners. Specifically, we aimed at assessing: 1) if the projects were assisted by scientists; 2) the source of the soils used in restoration (local or non-local); 3) the type of species used (native or non-native) and their provenance (local or other); and 4) if restoration success was evaluated, when, and how (which success indicators were used). We hypothesized that, despite the recent environmental policies and increasing scientific knowledge on ecological restoration, these are still not fully incorporated in restoration practice, namely in the Mediterranean Basin. For each restoration issue assessed we tested the following specific hypotheses: (i) projects differ in the extent to which they follow ecological restoration recommendations; and (ii) restoration practice is influenced by project location (within the EU or not), aridity level and cause of degradation. We thus expected to obtain a comprehensive overview of the current practice of ecological restoration projects implemented in this vulnerable region, in order to critically analyse to what extent they fulfill ecological restoration principles which will allow us to draw lessons to improve ecological restoration practice.

2. Material and methods

2.1. Questionnaire contents and dissemination

We built an open on-line survey about ecological restoration of drylands focused on practice. It addressed many aspects of restoration such as context and motivation, planning, implementation and maintenance, species selection, monitoring and success evaluation, and costs and benefits. The questionnaire was in English and consisted mostly of multiple-choice questions (with a free text option), including open-end and dichotomous (yes/no) questions (Appendix A1). The survey was sent out by e-mail and was also advertised on specific sites, with a link to the questionnaire form. Taking advantage of COST Action ES1104 ('Arid lands restoration and combat of desertification: setting up a drylands and desert restoration hub') contact network, we selected as wide a range as possible of professionals involved in ecological restoration of drylands, including practitioners from private companies and associations, governmental administrations, universities and research institutes, and thematic networks already established (e.g. the International Society for Ecological Restoration, DesertNet International, UNCCD and the European Society for Soil Conservation). The questionnaire was sent to 1431 contacts and 148 of them were returned. The information from the completed questionnaires was then collected and analyzed. Here, we focus on the questionnaires from ecological restoration projects implemented in the Mediterranean Basin ($n = 36$), which are mostly located in dryland areas ($n = 31$), and a few in non-dryland areas ($n = 5$).

2.2. Data analysis

The results are presented either as the relative proportion of the restoration projects addressed by the survey displaying a particular answer, or as the 'number of paired answers'. For multiple-choice answers, the sum of the relative proportions calculated for each option often exceeds 100% because the options are not mutually exclusive. The 'number of paired answers' corresponds to the number of times a certain pair of options is chosen simultaneously as a response to two distinct multiple choice questions. Therefore, the number of paired answers reflects the counting of options' combinations, and their sum may surpass the total number of projects addressed by the survey.

To integrate the information collected from several questions and classify the projects in terms of compliance with ecological restoration principles, we calculated an *ecological restoration practice index*. The index was based on six restoration issues addressed in the questionnaire clearly associated with ecological restoration recommendations (SER, 2004), and whose answers were independent of the respondent subjective opinion. The issues addressed were: (i) scientific assistance to restoration projects, as it is important to integrate the current knowledge about ecosystems' complexity and functioning in restoration practice; (ii) the source of the soil used in restoration, as it contains propagules thus playing a crucial role in the evolution and sustainability of the restored ecosystem; (iii) the type of species used, considering the preferential use of native species; (iv) the provenance of species propagules, considering the desirable conservation of species' genetic and functional trait diversity; (v) restoration success evaluation, as the only way to learn from experience, adapt management strategies and optimize restoration practice; and (vi) restoration success indicators used, preferably linked to ecosystem functioning and thus to its sustainability.

We attributed a score to each answer received (from 0 to 2), and the higher the score, the higher the agreement between the practice and ecological restoration principles. The final index value corresponds to the average of the scores we attributed to the six issues, as follows:

(i) scientific assistance to the project (before, during, and after the restoration project = 2; only in one or two of such occasions = 1; never = 0);
(ii) source of the soil used in restoration activities (only local = 2; local + other = 1; only non-local = 0);
(iii) type of species used (only native = 2; native + non-native = 1; only non-native = 0);
(iv) plant propagules' provenance (local = 2; local + other = 1; only national or international = 0);
(v) duration of monitoring for success evaluation (>5 years = 2; 1–5 years = 1; never = 0);
(vi) indicator(s) used to evaluate restoration success (based also on functional indicators, e.g. soil organic matter, litter decomposition rate, soil microbiologic diversity = 2; based only on species diversity, e.g. multi-taxa = 1; based only on diversity, vitality or cover of plant species = 0).

For data analysis, we used an estimate of the aridity index (the ratio of mean annual precipitation to annual potential evapotranspiration) for the period 1950–2000 for each restoration site. Aridity was retrieved from a global database (Trabucco and Zomer, 2009), based on the approximate geographic location of each project.

2.3. Statistical analysis

We built generalized linear models (GZLM) using binomial distribution and the logit link function to test the importance of aridity (aridity index), project location (countries inside and outside EU), and cause of degradation (overgrazing/agriculture, infrastructure/industry and fire) for all the studied variables, coding each category of the response variables as dummy variables (binary, 0 or 1). We used general linear models (GLM) to test the importance of the same explanatory variables (aridity, location and degradation cause) for the *ecological restoration practice index*.

By stratifying *a posteriori* the answers according to explanatory variables of interest (e.g. geographic location), we got unbalanced sample sizes which reduced the power of the statistical tests in some cases. Whenever the sample size was too low (e.g. $n < 5$), the interpretation of the results took this into consideration. All the analyses were performed under R statistical environment (Team RC, 2015).

3. Results

3.1. Characterization of restoration projects and of respondents

Here, we analyse the answers from 36 restoration projects implemented in terrestrial ecosystems distributed over 16 countries mostly from the Mediterranean Basin. We have included two projects not strictly belonging to this region (Georgia and Armenia), because of their geographic proximity and climatic similarity; 23 projects were from European Union (EU) countries, while 13 were from non-EU countries (nEU) (Fig. 1, Table 1).

Projects implemented in drylands were mostly from semi-arid areas (n = 20), followed by dry sub-humid (n = 7) and arid areas (n = 4), whereas 5 projects were from non-dryland areas, i.e. with an aridity index >0.65 (Middleton and Thomas, 1992) (Table 1).

Most projects encompassed more than one vegetation type, e.g. shrublands intermingled with perennial and annual grasslands (Table 1). Overall, the most represented habitats were shrublands (56%), annual grasslands (33%), and forest/woodlands (31% of the projects). Perennial grasslands were represented in 19% of the projects, savannas and riparian habitats in 6% each, and dunes in 8% (Table 1, Fig. A1). The implementation areas of the projects varied considerably, ranging from 0.8 ha to 48,124 ha, and no significant association was found between the size of the project area and any of the restoration issues addressed (data not shown).

In general, the main causes of land degradation were overgrazing (33%), infrastructure development (33%) and intensive agriculture (31%), whereas industrial activities (i.e. quarries and pit mines) and fire were indicated each in 22% of the projects. Deforestation and climatic constraints (e.g. drought), in many cases associated with the former degradation causes, were noted in 33% and 17% of the projects, respectively (Fig. 2). No significant association was found between the degradation causes and the aridity level, or with the location of projects (Fig. 2, Table A2).

Overall, most restoration projects (39%) were motivated by the need to comply with general legislation. It was relatively more important in the EU than in nEU countries ($p < 0.01$), especially to regulate the rehabilitation of areas affected by industrial activities and associated deforestation, along with the initiative of the companies responsible for those activities (22% of all projects) (Fig. 3, Table A2). Many restoration projects (33%) were also fostered by governmental initiatives such as central or regional administrations or rural support programs. The pressure from public opinion (22%) and public health issues (11%) had greater relative importance in nEU countries than in EU countries ($p < 0.01$). A few projects were motivated by specific and usually more restrictive legislation regulating restoration activities in protected areas (e.g. natural parks) (14%) (Fig. 3).

Most of the respondents worked at universities or research institutes (n = 26) while the remaining worked in the private sector (n = 6), governmental institutions (n = 3) or non-governmental organizations (n = 1) (data not shown). The respondents were chiefly researchers or scientific consultants (64%), most of whom were ecologists (33%), soil scientists (22%) or forest engineers or agronomists (19%) (Table 2).

Restoration activities were primarily planned by scientists/researchers (39% of the projects), followed by Conservation or Forestry State Institutes technicians (16%), and by employees of the involved local company (12%). The implementation of restoration activities was mainly done by the latter (25% of the projects) (Table A3).

3.2. Soil source, species selection, provenance of propagules and revegetation techniques

Only 8% of all projects used non-local topsoil for restoration; this occurred only in areas where land degradation was due to infrastructure development or industrial activities. The majority of the projects utilised original topsoil already eroded or disturbed (75%), alone or in combination with undisturbed local soil (33%), or with the reintroduction of local topsoil before plant introduction (22%) (Fig. 4A). No significant differences were found in the soil source used in restoration projects between different aridity levels or locations (Table A2).

The majority of the projects surveyed relied on the introduction of plant species (89%, data not shown). Revegetation was made with nursery-grown seedlings in 69% of the projects, whereas 44% included seeding and 28% used local transplantations, regardless of the degradation cause (Fig. 4B). Hydroseeding (17%) was carried out exclusively in restoration actions following industrial activities (mining) or infrastructure development, in some cases associated with deforestation and drought. The introduction (inoculation) of biological soil crusts (BSC) was used in 14% of the projects; although no statistically significant differences were found, probably due to unbalanced and low number of samples in each case, the use of BSC was associated with degradation driven by infrastructure development (and consequent deforestation), overgrazing or intensive agriculture (Table A2). Grazing exclusion was used as a restoration strategy in 3% of the projects (Fig. 4B).

A higher percentage of projects used exclusively native species in EU countries than in nEU countries, both in terms of seedlings (48% and 20%, respectively; $p < 0.05$) and seeds (47% and 22%, respectively;

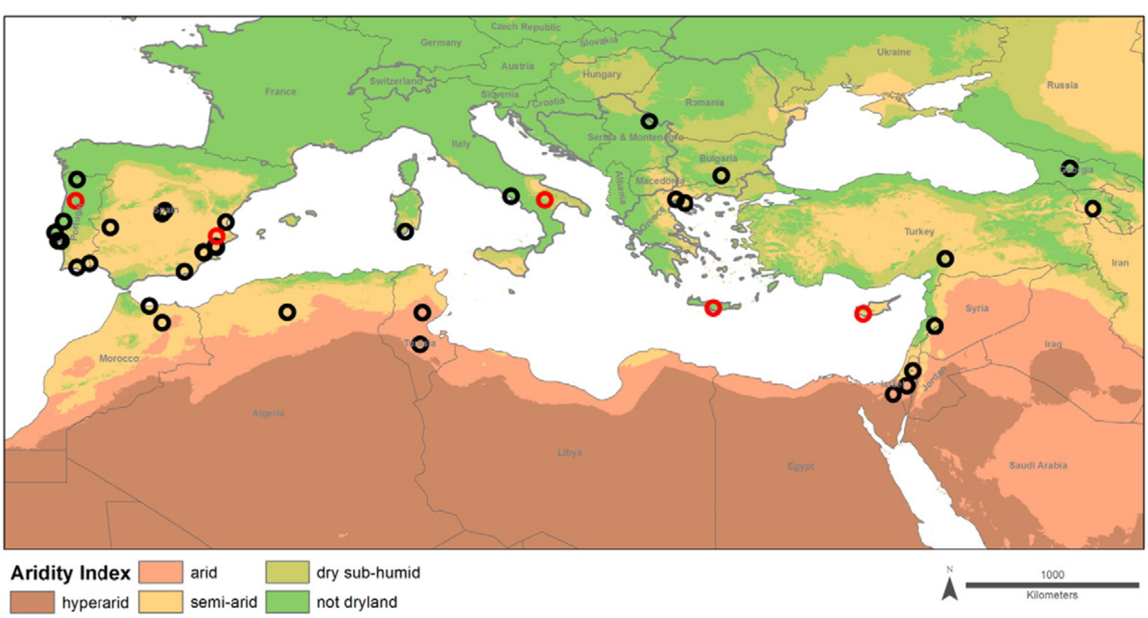

Fig. 1. Geographical distribution and aridity index of the surveyed ecological restoration projects. The red circles indicate five sites belonging to the same project (one questionnaire). More information about each project can be found in Table A1.

Table 1
Brief description of the surveyed restoration projects: context, country, classification according to the United Nations Environmental Programme (UNEP) aridity index, and habitat type (FW - Forest/Woodland; SR - Shrubland; SV - Savanna; AG - Annual grassland; PG - Perennial grassland; DN - Dunes; RP - Riparian).

Project context	Country	Aridity level	Habitat type						
			FW	SR	SV	AG	PG	DN	RP
Sand dune restoration	Israel	Arid						X	
Overgrazed lands	Israel	Arid				X			
Overgrazed agropastoral systems	Tunisia	Arid		X		X			
Deforested/overgrazed lands	Tunisia	Arid	X	X		X	X		
Deforested lands	Algeria	Semi-arid				X		X	
Quarry restoration	Greece	Semi-arid		X			X		
Quarry restoration	Greece	Semi-arid	X						
Overgrazed/burned lands	Italy	Semi-arid	X						
Overgrazed agropastoral systems	Morocco	Semi-arid		X					
Deforested/agricultural lands	Morocco	Semi-arid	X						
Deforested lands	Palestine	Semi-arid		X		X			
Agricultural/burned lands	Portugal	Semi-arid		X					
Quarry restoration	Portugal	Semi-arid			X				
Quarry restoration	Spain	Semi-arid		X					
Agricultural/burned lands	Spain	Semi-arid		X					
Overgrazed lands	Spain	Semi-arid			X				
Quarry restoration	Spain	Semi-arid	X	X		X	X		
Degraded orchards and vineyards	Spain	Semi-arid		X					
Deforested/agricultural lands	Spain	Semi-arid		X					
Overgrazed/burned lands	Spain	Semi-arid	X	X					
Agricultural lands	Spain	Semi-arid		X		X	X		
Burned lands	Spain	Semi-arid		X					
Deforested/overgrazed lands	Spain	Semi-arid		X					
Burned lands	Several[a]	Semi-arid	X						
Overgrazed pastures	Armenia	Dry subhumid				X	X		
Burned degraded lands	Bulgaria	Dry subhumid	X						
Overgrazed agropastoral systems	Lebanon	Dry subhumid				X			
Pit mine restoration	Portugal	Dry subhumid	X						
Quarry restoration	Portugal	Dry subhumid		X					
Burned/eroded lands	Serbia	Dry subhumid	X				X	X	X
Deforested/overgrazed lands	Turkey	Dry subhumid	X	X		X			
Agricultural/overgrazed lands	Georgia	Not dryland				X			
Deforested/eroded lands	Italy	Not dryland		X					
Deforested/eroded lands	Portugal	Not dryland		X					
Deforested/eroded lands	Portugal	Not dryland							X
Quarry restoration	Portugal	Not dryland		X		X	X		

[a] Portugal, Spain, Italy, Greece, Cyprus.

$p < 0.05$) (Fig. 5 A, B, Table A2). Conversely, more restoration projects used mainly non-native plant species in nEU countries when compared to EU countries, in terms of seedlings (10% and 40%, respectively; $p < 0.05$) and seeds (5% and 44%, respectively; $p < 0.05$) (Fig. 5 A, B, Table A2). No relationship was found between the nativeness of the species used in restoration and different aridity levels or degradation causes (Table A2).

The main reasons pointed out for the use of non-native species, which happened in 47% of the projects ($n = 17$), were a usually higher growth rate relative to native species (65%), and a greater commercial availability (47%) at a lower price (24%). Nurse-effects and aesthetic values were also reported each for 18% of the projects using non-native species (Fig. A2).

Most projects used nursery-grown saplings of local (42%) and regional (48%) provenance, and only 26% reported the use of saplings of national provenances (Fig. 5C). In contrast, most projects used seeds of national provenance (62%), while only 31% and 17% used seeds of local and regional provenances, respectively (Fig. 5D). The projects using seeds from international sources (14%) were implemented in less arid sites ($p < 0.05$) (Table A2), while no association was found between the propagules' provenance and degradation causes (Fig. 5D, Table A2).

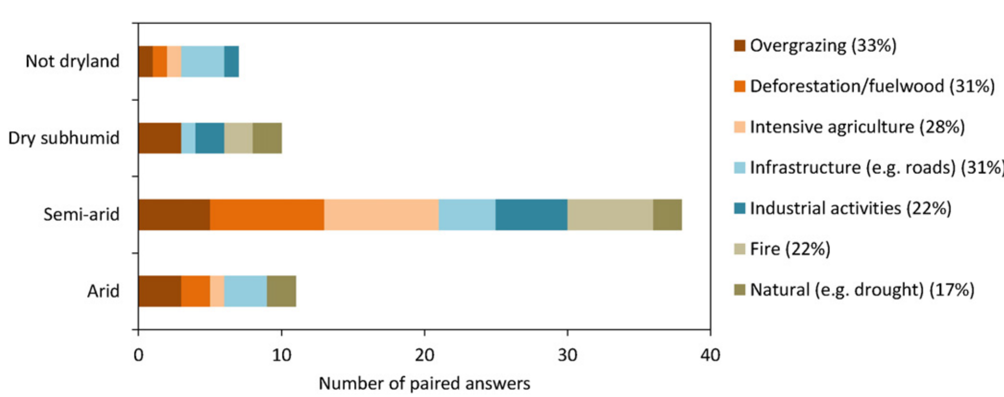

Fig. 2. Number of times each degradation cause was reported for each aridity level (number of paired answers). The overall relative proportion of restoration projects referring to each degradation cause is displayed within brackets.

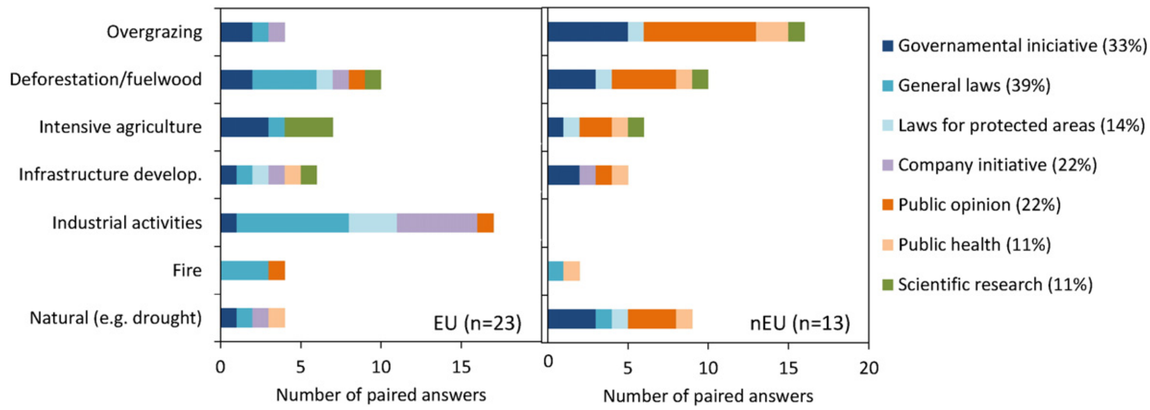

Fig. 3. Number of times each restoration motivation was reported for each degradation cause (number of paired answers), for restoration projects from European Union countries (EU) and from other countries (nEU). The relative overall proportion of projects referring to each motivation is displayed within brackets.

3.3. Restoration monitoring and success evaluation

About one third of the projects (31%) did not include maintenance activities after plant introduction, while 27% had activities in the first year, and 37% had extended maintenance up to five years, which was roughly the upper limit reported (Fig. 6A). The duration of maintenance activities, including irrigation, control of disturbances (fire, grazing, pests), and control of undesired species through mechanical or chemical methods, showed no relationship with aridity levels (data not shown).

Restoration success was never evaluated in 22% of the projects, while about the same proportion evaluated this only in the first year after plant introduction (19%), or until the 5th year (22%). A low proportion evaluated results over the long-term (>6 years, 14%; >10 years, 17%) (Fig. 6A). Restoration success evaluation was mainly based on plant cover and diversity (69% of the projects) and plant vitality (48%) (Fig. 6B). The main indicators of ecosystem functioning - hereafter noted as ‘functional indicators’- were soil organic matter (41% of the projects) and nitrogen content (38%) (Fig. 6B). On average, 4 to 5 different metrics were used per project to evaluate restoration success. The respondent's answers indicated that in 77% of the projects there was no attempt to specifically quantify ecosystem services (data not shown).

Restoration efforts yielded partially unexpected results in 50% of the projects ($n = 18$). The main negative unexpected results were high plant mortality associated mostly with drought, low soil quality and erosion, and low or inadequate biodiversity (e.g. dominance of a species), mainly associated with drought (Table 3).

In many cases, restoration projects were considered partially (44%) or completely unsuccessful (6%), i.e. with their aims only partially achieved or not fulfilled at all. Success perception was not related to the background of the respondent nor with the aridity level.

The *ecological restoration practice index* was significantly higher in areas degraded by infrastructure development (e.g. roads) or by industrial activities (quarries) in EU countries than in nEU countries ($p < 0.05$) (Fig. 7). This was mostly due to a higher use of non-native species and of propagules of exogenous provenances, and to a shorter-term evaluation of restoration success in nEU countries (Fig. 7). Restoration after industrial activities had a higher index than that of burned lands in EU countries ($p < 0.05$), mainly due to the lack of success evaluation, especially in the long-term (>5 years), and of scientific assistance to restoration, in the latter case (Fig. 7). This index was not significantly correlated with the aridity level.

4. Discussion

This survey across the Mediterranean Basin provided an overview of the current practice of ecological restoration projects implemented in terrestrial ecosystems in the region. General overviews over large geographical areas can provide a critical perception on what is needed to improve restoration efforts. Although the survey was directed towards ecological restoration projects, in some cases it may be difficult to confirm that the type of restoration implemented was ‘ecological’, in the sense advocated by the Society for Ecological Restoration (SER, 2004). We decided to rely on the practitioner's judgment and we acknowledge this limitation. We nevertheless found considerable differences among projects in the degree to which they follow ecological restoration principles.

Many restoration projects implemented in EU countries were primarily motivated by legislation requirements. This is probably related to legal initiatives and policy targets developed in recent years regarding biodiversity conservation within the European Union. In non EU countries (nEU), public opinion and health were more important motivations for ecological restoration projects than in EU countries. Land degradation associated with intensive land use (e.g. overgrazing, intensive agriculture) decreases productivity and has direct negative impacts on people's livelihood and income, which may explain a growing social involvement in restoration issues calling for more sustainable land management approaches (Derak et al., 2016).

The first step of restoration activities concerns soil, as the primary support of terrestrial ecosystems (Costantini et al., 2016). Only 8% of

Table 2
Characterization of the survey respondents regarding their academic background and role in the restoration project.

Background	Company representative	Project manager or coordinator	Researcher/consultant	Total percentage
Ecologist		1	11	33.3%
Soil engineer/scientist		3	5	22.2%
Forest engineer/agronomist	1	3	3	19.4%
Geoscientist	1		2	8.3%
Environmental-social scientist		1	2	8.3%
Industrial technician	2			5.6%
Biochemist		1		2.8%
Total percentage	11.1%	25.0%	63.9%	

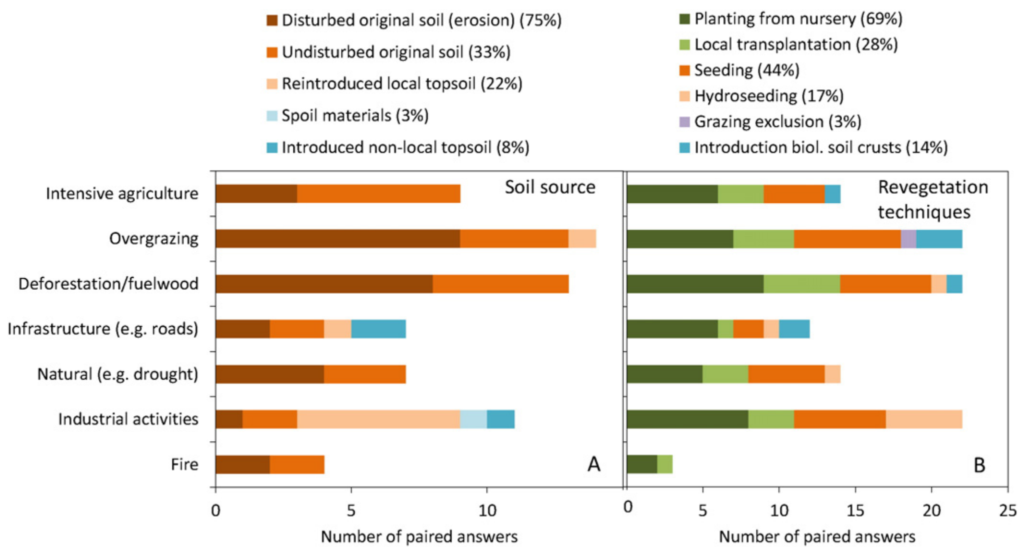

Fig. 4. Number of times each soil source (A) and revegetation technique (B) was reported for each degradation cause (number of paired answers). The relative overall proportion of restoration projects referring to each soil source (A) and revegetation technique (B) is displayed within brackets.

the projects reported the use of non-local soil, and were associated with restoration after infrastructure development (e.g. roads) and industrial activities (e.g. quarries), which often entail the complete removal of topsoil in large areas. In such cases, it is very important to save and properly 'store' original soils to be reintroduced later, in the restoration process, otherwise the use of exogenous soil, although unadvisable, becomes frequently inevitable. The use of local topsoil presents many advantages in comparison with exogenous soil. No matter how degraded, unstructured and depleted it may be, it carries propagules of locally adapted species and the associated soil fauna and flora, exhibiting a higher potential to enhance natural colonization and succession as well as biotic interactions in the restored ecosystem, after active restoration interventions take place. On the contrary, exogenous soils may carry propagules of exotic species, which might lead to unexpected and often negative restoration outcomes (Rowe, 2010; Tischew et al., 2011).

Most of the Mediterranean Basin is subject to low water availability, which severely constrains the natural recovery of vegetation. This might explain why the majority of the projects surveyed relied on the introduction of plant species, presumably to (partially) overcome that limitation and thus promote the subsequent restoration of the whole biological community (e.g. animal species). Restoration projects implemented in EU countries relied more on native plant species (both saplings and seeds) than in nEU countries. This may be related with the need to comply with the aforementioned EU legislation regarding biodiversity conservation. Conversely, nEU countries used, in general, more non-native species. The main reasons for this preference were their frequently higher relative growth rates when compared to native species, and external factors such as a higher commercial availability and lower price, as well as, to a lesser extent, their aesthetic value and alleged nurse-effect as facilitators of the establishment of other species (Nunes et al., 2014). Regardless of the legitimacy of these arguments (Davis et al., 2011; Rowe, 2010; Tischew et al., 2011), they diverge from ecological restoration principles, which advocate the use of native species to the greatest practicable extent (SER, 2004). This is not only because indigenous species are adapted to local edaphic and climatic

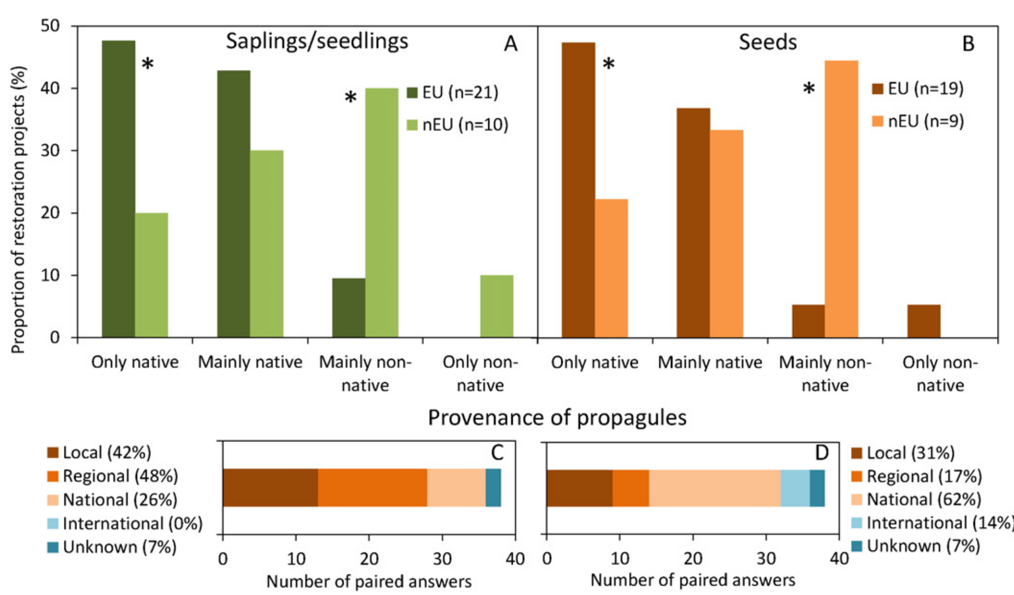

Fig. 5. Upper panel: Proportion of projects using each type of plant species (native or non-native) and propagule (nursery-grown saplings/seedlings, A; seeds, B); values are compared between EU and nEU countries (GZLM results, $^{*}p < 0.05$). Lower panel: Frequency of provenance class reported for saplings/seedlings (C) and seeds (D). Local provenance corresponds to a <10 km distance from the restored site. The relative overall proportion of projects referring to each class of provenances for saplings (C) and seeds (D) is displayed within brackets.

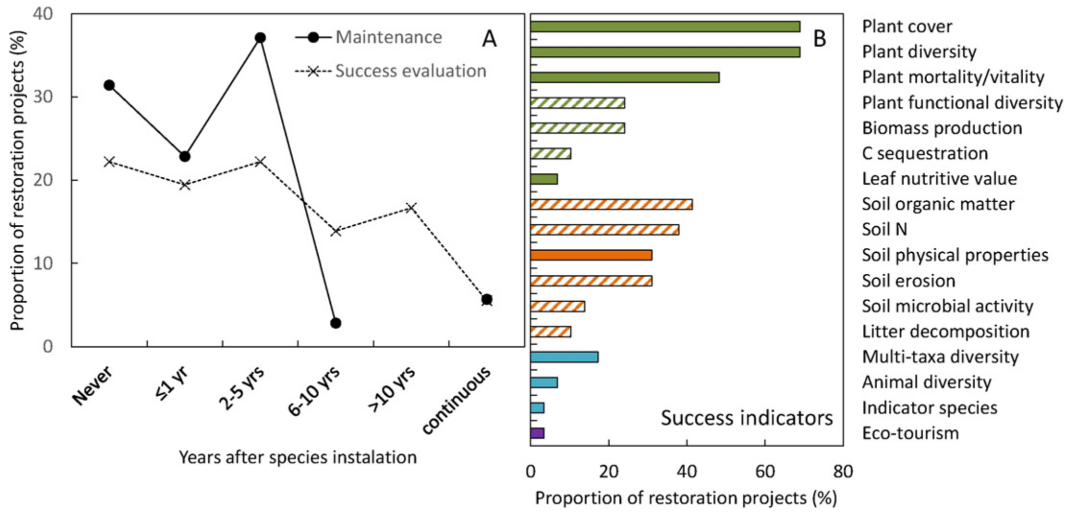

Fig. 6. Proportion of projects with maintenance and success evaluation activities after plant introduction (A), and indicators used to measure restoration success (B), based on plant (green), soil (orange) and other information (blue and purple); solid bars correspond to non-functional indicators, and striped bars correspond to functional indicators.

conditions and play a positive role in the network of local biotic interactions, necessary for ecosystem sustainability and resilience (Tischew et al., 2011), but also because the use of exotic species often entails ecological risks and may compromise the success of the restoration actions (Alyokhin, 2011; Rowe, 2010; Shackelford et al., 2013). Used for restoration, such species may become dominant (or favour the dominance of undesired species) and outcompete native species (e.g. Nunes et al., 2014), as reported in some of the surveyed projects. Additionally, they may have a negative impact in biotic fluxes and interactions with local flora and fauna (Alyokhin, 2011), thus hindering natural colonization and succession, which should be promoted and capitalized as much as possible.

Young plants used in restoration activities were mostly of local or regional provenance, probably also for logistic reasons, but plant seeds were not, as is often the case in many restoration projects (Kiehl et al., 2010; Oliveira et al., 2012; Tischew et al., 2011). Although the use of generalist and easily commercially available 'seed recipes' of exogenous or unknown provenances is a common practice particularly in large-scale restoration projects, it may lead to the loss of local diversity of adapted varieties and possibly alter ecosystem functions (Bischoff et al., 2010; Rowe, 2010; Vander Mijnsbrugge et al., 2010). Local plant varieties exhibit morphological and functional traits which determine their fitness (Bischoff et al., 2010), enabling adaptation to the harsh climate of drylands and to other disturbances. Moreover, species traits greatly influence ecosystem functions (Mason and de Bello, 2013). It is therefore advisable to promote genetically diverse local provenances in restoration projects, particularly in the context of harsh environmental conditions (Vander Mijnsbrugge et al., 2010). For such purposes, the availability and ability to collect local seeds should be promoted (Kiehl et al., 2010; Tischew et al., 2011; Vander Mijnsbrugge et al., 2010). In addition, when the quantity of locally collected seeds is insufficient, e.g. for the restoration of large areas, seed collection from habitats with similar climates and geomorphologies, even if distant, might be an option (Vander Mijnsbrugge et al., 2010). The provenance of propagules for restoration projects is expected to be particularly relevant in species adaptation to climate change, which is predicted to severely impact Mediterranean Basin ecosystems (IPCC, 2007). Recent works suggest that, in a climate change scenario, provenances from slightly different climates might be necessary to facilitate plant adaption (e.g. assisted gene flow) (Breed et al., 2013). However, regardless of its value, this view still lacks consistent evidence from scientific research, e.g. from long-term experiments, to fully assess the feasibility and success of such a seed-sourcing strategy (Breed et al., 2013; Hodgins and Moore, 2016).

Fifty percent of the restoration projects faced unexpected results, such as high plant mortality or low or inadequate biodiversity. This highlights our still low predictive ability concerning restored ecosystems trajectories and outcomes (Suding et al., 2015). Despite recent progress in bringing the science and the practice of restoration closer to each other (Cabin et al., 2010), we need to improve our understanding of ecosystems complexity, and invest further in its integration into ecological restoration practice. In this context, monitoring is an essential tool, as it is necessary to evaluate restored systems trajectories and adopt flexible management strategies whenever necessary (adaptive management) to redirect the restoration course and meet the predefined restoration goals. It is the only way to learn from examples (both successes and failures) and improve restoration practices. Nevertheless, 22% of the projects made no evaluation of the restoration outcome, and only a low proportion (31%) evaluated it for more than six years after plant introduction, coinciding with the end of maintenance activities in the majority of the projects. This makes it impossible to monitor the so-called 'slow variables' (Carpenter and Turner, 2000),

Table 3
Number of times each probable cause was reported for each unexpected negative result in the restoration projects (number of paired answers) ($n = 18$). The darker the color the higher the value.

Probable causes	High mortality	Low or inadequate biodiversity	Dominance of a native species	Low plant cover	Low natural recruitment
Drought	11	4	3		1
Low soil quality	7	1	1		1
High erosion	3	1	1	1	1
Pests	2	1	1		
Inappropriate planting techniques	2	1	1		
Excessive irrigation		1			
Wildfire	1				
Invasive species		1			
High fragmentation				1	
Short elapsed time				1	

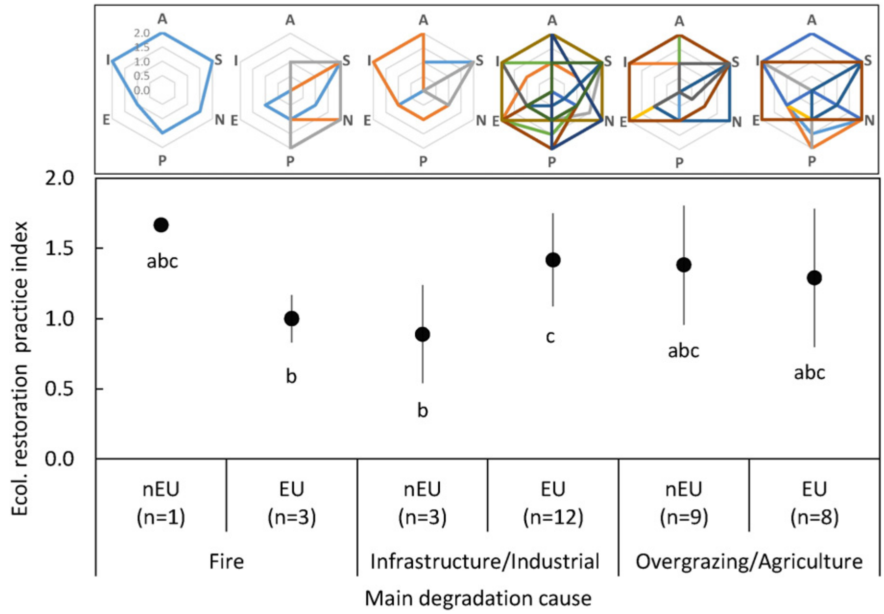

Fig. 7. Ecological restoration practice index (mean ± SE) calculated for each main degradation cause in EU and nEU countries. This index varies from 0 to 2 and is the average of the scores of the answers to six questions related to: scientific assistance (A), soil source (S), species nativeness (N), species provenance (P), timing of success evaluation (E) and success indicator(s) used (I) (see Material and methods for further details). Different lowercase letters indicate significant differences among means (GLM results, $p < 0.05$). The number of projects represented in each group is indicated (n). The upper panel shows the score of each question (uppercase letters) for the projects included in each group, and each project is represented by a different color.

some of which are critical to the dynamics of dryland ecosystems and key to their functional recovery (e.g. soil fertility) (Reynolds et al., 2007b). The long-term monitoring of restoration projects depends on the stakeholders involved and particularly on the funding available to implement it. Hence, it is crucial that restoration plans include and ensure funding to support monitoring programs during an adequate number of years after restoration.

Moreover, the success of restoration in most projects was primarily based on plant species cover and diversity (69%), while few projects used functional indicators, despite the relatively frequent measurement of soil organic matter and nitrogen content (41 and 38%, respectively). Functional indicators are directly linked to ecosystem functions, i.e., dynamic attributes affecting the fluxes of energy and mass (solids, water and nutrients), which are the basis for the self-maintenance of an ecosystem. Examples are primary productivity, trophic interactions, decomposition, and nutrient cycling. According to ecological restoration principles, ecosystem functioning is key because it ensures sustainability over the long term. Moreover, the ability to deliver diversified ecosystem services, not only the provisioning services (e.g. food, fuelwood, fresh water), but also the regulation and maintenance services (e.g. drought and flood buffering, genetic diversity, carbon sequestration), and cultural services (e.g. tourism, recreation) (Haines-Young and Potschin, 2013), depends on ecosystem functioning (Groot et al., 2013; Lavorel and Grigulis, 2012). Hence, functional indicators such as the presence and abundance of critical functional groups or traits, decomposition rates, soil microbiological activity, just to mention some examples, should be included in restoration monitoring programs. Interestingly, although ecosystem services' delivery was frequently pointed out as one of the restoration goals (data not shown), in 77% of the projects no attempt was made to specifically quantify them. Nevertheless, ecosystem services assessment can be a way for practitioners to emphasize socio-economic benefits of restoration as a worthwhile investment for society (Groot et al., 2013). Long term monitoring and evaluation of both biophysical and socio-economic ‘slow’ variables (Carpenter and Turner, 2000) are therefore important to fully assess restoration success.

The *ecological restoration practice index* we built, based on six important components of ecological restoration practice, enabled us to conclude that, although all projects claimed to follow ‘ecological restoration’ guidelines, they varied considerably and differed in some procedures. The areas degraded by infrastructure building or industrial activities had a higher mean restoration practice index in EU countries than in nEU countries, mainly because EU countries, in general, relied more on native species and propagules of local provenance, and on longer evaluation of restoration success (>5 years), despite the much smaller number of replicates in the second case. This can be associated with EU environmental policies, translated into more legislation targeted at local biodiversity conservation. Restoration after industrial activities also had a higher index than that of lands affected by fire in EU countries, and this was mainly associated with the lack of long term success evaluations and of scientific assistance to restoration in the latter. This may be associated with the high resilience and generally fast recovery of Mediterranean ecosystems after fire, probably weakening the perception of the need for long-term evaluation, despite the small number of projects analysed in these conditions.

The unbalanced geographical distribution of the answers obtained across the Mediterranean region (e.g. a higher number of cases from the Iberian Peninsula) and the low number of replicates in some cases, may have prevented the emergence of clearer or more robust trends regarding restoration practice. Although it is the most used language for scientific communication, English (also used in the questionnaires) may have discouraged the participation of some restoration practitioners (e.g. from francophone countries in North Africa), particularly those not involved in scientific research.

5. Conclusions and implications

By collecting information on the practice of ecological restoration projects implemented in terrestrial ecosystems across the Mediterranean region, we identified considerable variability in restoration procedures, in some cases closer to fulfill ecological restoration principles than others. Our work is a step forward in understanding what is going on in restoration practice, and the work has produced some indications on what is needed to improve and promote ecological restoration efforts in Mediterranean areas, particularly in drylands.

Sharing technical information about restoration practice, including unexpected results in restoration, problems, and successful solutions, and making it readily available to other practitioners, is crucial to improve restoration practice.

Considering the potential risks of the use of non-native species and of genetically uniform varieties in ecological restoration actions, a cautious approach is required. The use of native species and of local propagules in restoration plans should be promoted, particularly in countries outside the European Union. This calls for increased awareness among restoration practitioners (e.g. technicians, local people) on the importance of such species for local adaptation to climate and other disturbances, particularly in a context of a changing environment, as well as to promote biotic interactions and ecosystem sustainability and resilience. To achieve this, regulated collection and commercial availability of local propagules of native species should be promoted, thus hopefully contributing to reduce their prices.

Monitoring and evaluation should be priorities for all restoration projects, as this is the only means to learn from experience, detect undesirable outcomes and flexibly adopt management strategies to cope with them. Since much is still unclear regarding restored ecosystems' trajectories and evolution, evaluation in the medium/long term is also essential, in order to monitor 'slow' ecosystem variables (e.g. soil fertility) which are often crucial in dryland ecosystems. Hence, it is important to consider and ensure appropriate funding for long-term monitoring of restoration projects. As long as ecological restoration is the aim, an evaluation of the restored ecosystems focused on ecosystem functioning (i.e. using 'functional' indicators) is indispensable to assess and ensure, as far as possible, their sustainability and resilience over the long term, particularly under a climate change scenario. Considering that ecosystem services' delivery was frequently pointed out as one of the restoration goals, the inclusion of indicators of ecosystem services in monitoring protocols would match this claimed goal, as well as increase society's awareness of the importance of restoration.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2016.05.136.

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