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ORIGINAL ARTICLE

Lichen diversity on dolmen and menhir in the Megalithic complex of Sa Coveccada (Mores, Sardinia)

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Abstract
This work describes the lichen diversity found on the megalithic Dolmen of Sa Coveccada (Mores, Sardinia) until 2010. After that year, a restoration with chemical removal of lichen crusts took place, which destroyed a great part of the lichen communities. These were studied again after removal and lichen communities occurring on rock outcrops in the surroundings of the Dolmen and on a contiguous menhir were investigated as well for comparison. Before the restoration, 33 species had been recorded on the Dolmen, most being crustose, followed by foliose and fruticose forms. Among these, eight species are regarded as rare in Sardinia and five rare at lower elevations. Most of the recorded species are typical for eutrophic substrates and for meso- to xerophytic conditions. Studies on lichen diversity on archaeological monuments in Sardinia are limited. This is the first report on the lichens of a Sardinian dolmen. This paper questions whether the lichen diversity of such monuments should be preserved as lichens have been an important part of the monument ecosystem and of the landscape for many centuries. This work also aims to improve collaboration among lichen and monument experts, in order to avoid hasty restoration decisions.

Keywords: *biodiversity, dolmen, Italy, lichens, monument, Sardinia*

Introduction

Many lichen species contribute to the deterioration of a wide range of stony materials due to both physical and chemical processes. From a natural point of view, this is a common and useful ecosystem function of lichens, which promotes pedogenetic processes, nutrient cycling and vegetation recolonization by bryophytes and plants (Piervittori & Laccisaglia 1993), but it becomes a problem when artworks with historical value are damaged.

Mechanical damage can occur in 10 years or less, due mainly to foliose and crustose lichens (Seaward & Giacobini 1988). The rhizines of foliose lichens can generate pressures in the rock, while crustose lichens, being adherent within or on the substratum, can cause damages linked to the penetration of hyphae, the widening of pores and the consequent rock decohesion (de los Ríos et al. 2009). Furthermore lichens are poikilohydric organisms; therefore, the thallus can expand or contract in relation to water availability or to freezing and melting processes (Gehrmann et al. 1988; Caneva et al. 2005a).

Chemical damages play also an important role in rock deterioration. They are mainly due to the activity of acids and secondary metabolites produced by lichens, causing the corrosion or alteration of minerals through processes of hydration, oxidation, dissolution, e.g. of carbonates, and solubilization of elements. Oxalic acid, in particular, is considered as one of the most biodeteriogenous substances produced by lichens (Piervittori & Laccisaglia 1993), but all species known from literature to be active in rock decomposition, even if unable to produce biodeteriogenous acids or lichen substances, should be taken into consideration in restoration plans (Gazzano et al. 2009).

Also the geological nature as well as the chemical and physical structure of a stone can influence the intensity of weathering effects (Warscheid & Braams 2000). According to some authors, in some cases, the lichen canopy could even protect the substratum from other deterioration factors such as atmospheric

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agents and pollutants (Piervittori & Sampò 1988). In fact, the limitation of water exchange between substratum and environment due to lichen crusts may control the natural degradation of porous stones of human artefacts by water erosion (Caneva et al. 2005a). They can also protect the stone from wind erosion and often their mechanical action is limited due to the slow growth rates (Ozenda & clauzade 1970; Pallecchi & Pinna 1988).

There are no former studies analysing lichen diversity on Sardinian dolmens, but previous studies on lichen biodeterioration were carried out both in Portugal, on two granitic dolmens (Romão & Rattazzi 1996), and in Galicia (north-west Spain), on five granitic dolmens (Prieto Lamas & Silva 1994). In Sardinia, lichens growing on nuragic monuments were reported by Nimis and Poelt (1987) and by Tretiach and Monte (1991) and Tretiach et al. (1991), who elaborated a new hygrophytism index based on lichen species colonizing nuraghes in NW Sardinia. A rich bibliography on lichens and monuments concerning biodeterioration and recolonization by lichens after restoring works is available for Italy and at the international level (e.g. Seaward et al. 1990; Nimis et al 1992; Piervittori & Laccisaglia 1993; Nimis & Salvadori 1997; Piervittori et al. 2004, 2009; Warscheid & Braams 2000; Nimis 2001; Caneva et al. 2005a, 2005b; Nascimbene & Salvadori 2008; de los Ríos et al. 2009; Gazzano et al. 2009; Nascimbene et al. 2009). Numerous works are, also, available on lichen biodeterioration on different types of rocks (Nimis & Tretiach 1996; Favero-Longo et al. 2005, 2011, 2013) and on techniques for their removal (e.g. Tretiach et al. 2007, 2010, 2012).

The object of this investigation is the megalithic complex of Sa Coveccada (Mores, northern Sardinia), comprising a dolmen, which was subjected to a restoration work, and a menhir. The aims of the study are: to report on the lichen diversity colonizing the dolmen of Sa Coveccada before restoration, to question whether the biodiversity of such monuments should be preserved, as lichens have been an important part of the monument ecosystem and of the landscape for many centuries and to improve collaboration among lichen and monument experts, in order to avoid hasty restoration decisions. The lichen diversity found on the rocky outcrops and on monuments is also compared to point out differences in the occurrence of species, in particular of the rare ones.

Materials and methods

The megalithic complex of Sa Coveccada is located at Mores (northern Sardinia) (altitude: 280 m, longitude: 32T 488705; latitude: 4484173) and dates back to the third millennium B.C. It is composed by a dolmen and a menhir. The dolmen, ca. 3 m high and ca. 5 m wide, is the biggest monument of this type in Sardinia and one of the biggest of the Mediterranean area. It is made of ignimbrite (Professor Giacomo Oggiano, pers. comm.), and composed of three big upright stones (a fourth is missing) and of a large flat horizontal capstone (Atzeni 1966; Bittichesu 1998; Basoli et al. 2011) (Figure 1).

According to Arrigoni (1968), the locality is part of the mesophilous horizon of *Quercus ilex* L. forests, characterized by a typical bi-seasonal weather with sub-humid to moderately cold winter and hot summer with high water deficit. In the surroundings of the dolmen, there is farm land with herbaceous vegetation grazed by sheep, pigs and horses. Rock outcrops are part of an ignimbritic plateau. A stone wall is present in the nearby valley as well several fenced private land parcels. In proximity of the dolmen, there are three little stones that are likely part of the monument, and a menhir is found in the near valley.

The Superintendence for Architectural, Landscape, Historical, Artistic and Ethno-Anthropological Heritage of the provinces of Sassari and Nuoro started a restoration work of the dolmen in 2010. This included its cleaning with compressed air, disinfestations with non-polluting and not poisonous chemicals against biodeteriogens, and infiltrations of a consolidating material to fill the cracks and fissures caused by atmospheric agents (Basoli et al. 2011).

Before the restoration started, the Department of Science for Nature and Environmental Resources of the University of Sassari was consulted by the Mores municipality to evaluate the diversity of lichen species growing on the dolmen and to estimate the

Figure 1. Dolmen of Sa Coveccada.

possible deterioration caused by them. By the first two surveys in summer 2010, lichen communities were still intact, and it was possible to collect samples for species identification in a minimally invasive way. During a third investigation in May 2011, most lichens had been removed, which made the evaluation of their impacts on the monument impossible.

Samples of the lichen species present on the dolmen were collected in July 2010 and during a second survey in August 2010. Parts of the thallus and the fruiting bodies (if present) of each species were removed using razor blades, without creating damage to the monument and the lichens.

Photos of lichen communities were taken during both surveys. During the third visit (May 2011), a photographic documentation of the damage caused on lichen communities by the restoration interventions was done. Another survey was made in 2012, to investigate the lichens growing on the rock surroundings of the dolmen and in the near menhir. Further, photographic material and some lichen specimens were collected to underline possible differences in lichen composition among dolmen, menhir and rock outcrops.

The gathered samples were identified in the laboratory using different identification keys (Ozenda & Clauzade 1970; Clauzade & Roux 1985; Nimis 1986; Purvis et al. 1992; Nimis & Bolognini 1993; Pant & Upreti 1993; Rambold et al. 2001–2014; Giordani et al. 2002; Nimis & Martellos 2008; Nordin et al. 2010). For nomenclature, we referred to the databases Bioscience Species Fungorum (Kirk 2012) and Nimis and Martellos (2008), the latter was used also to gain information on rarity status, distribution and ecological indices (e.g. solar irradiation, aridity and eutrophication) of each species. The final indices for each species were calculated as the average of the values indicated by the above cited authors (Figure 2).

Results

During the first two investigations in 2010, before the start of the restoration interventions, 33 infrageneric taxa of lichens were recorded on the dolmen. These were mainly crustose (51.5%), followed by broad-lobed foliose (21.2%), fruticose (15.2%), narrow-lobed foliose (6.1%), one (3%) foliose umbilicate species and one (3%) lichenicolous fungus. Endolithic species were not found on the monument. Most of the species reproduce sexually (57.6%), 24.2% reproduce vegetatively by soredia and 18.2% by isidia. Among the species found, 59.4% are common or very common, 25% are rare in Sardinia, 15.6% are only rare at lower elevations (Table I).

The menhir hosts 18 species, 55.6% of them being crustose, 27.8% broad-lobed foliose, 5.6% narrow-lobed foliose and 11% fruticose (*Ramalina*). Most lichens found on the menhir reproduce sexually (61.1%), 22.2% vegetatively by isidia and 16.7% by soredia. Most species are considered as common

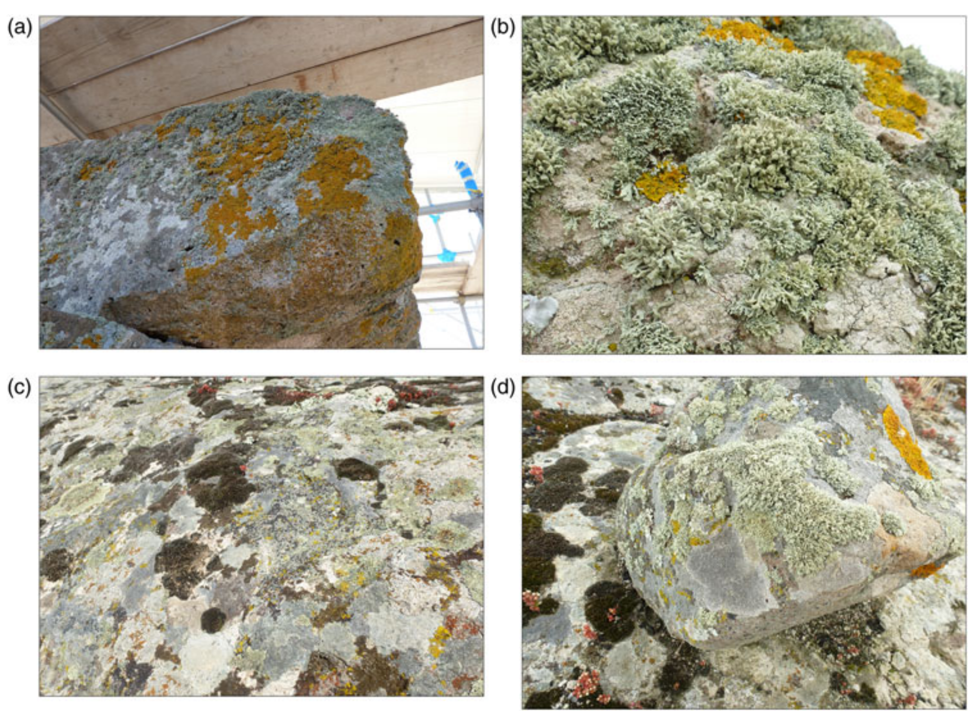

Figure 2. Particular of the capstone of the Dolmen of Sa Coveccada (A); particular of the menhir (B); particular of the rocks nearby the dolmen (C); particular of stones near the dolmen (D).

Table I. The species collected on dolmen, menhir and surrounding rock outcrops are listed alphabetically.

Species	Dolmen	Menhir	Outcrops	Growth form	Reproduction	Rarity status
Acarospora badiofusca (Nyl.) Th. Fr. subsp. *badiofusca*	0	1	1	cr	S	r
Acarospora veronensis A. Massal.	1	0	1	cr	S	r
Amandinea punctata (Hoffm.) Coppins & Scheid.	1	0	0	cr	S	c
Aspicilia caesiocinerea (Nyl. ex Malbr.) Arnold	1	0	1	cr	S	c
Aspicilia sp.	0	1	0	cr	S	n.a.
Caloplaca crenularia (With.) J.R. Laundon	1	1	1	cr	S	c
Caloplaca inconnexa var. *nesodes* Poelt & Nimis	1	0	1	lich.f.	S	c
Candelariella coralliza (Nyl.) H.Magn.	0	1	0	cr	S	r
Candelariella vitellina (Hoffm.) Müll. Arg.	1	1	1	cr	S	c
Diploschistes actinostomus (Ach.) Zahlbr.	1	0	0	cr	S	c
Lasallia pustulata (L.) Mérat	1	0	0	fo.um	A.i	r (low alt)
Lecanora campestris (Schaer.) Hue.	1	0	1	cr	S	c
Lecanora cf. *dispersa* (Pers.) Sommerf.	0	1	1	cr	S	c
Lecanora rupicola (L.) Zahlbr.	1	0	1	cr	S	c
Lobothallia radiosa (Hoffm.) Hafellner	1	0	0	cr	S	c
Melanelixia fuliginosa (Fr. ex Duby) O.Blanco, A.Crespo, Divakar, Essl., D.Hawksw. & Lumbsch	1	1	1	fo.br	A.i	c
Ochrolechia parella (L.) A.Massal.	0	1	0	cr	S	c
Parmelina tiliacea (Hoffm.) Hale	1	1	0	fo.br	A.i	c
Pertusaria flavicans Lamy	1	0	0	cr	A.s	r
Pertusaria pertusa v. *rupestris* (DC.) Dalla Torre & Sarnth.	1	0	0	cr	S	c
Pertusaria pseudocorallina (Lilj.) Arnold	1	0	0	cr	A.i	r
Phaeophyscia orbicularis (Neck.) Moberg	1	0	0	fo.na	A.s	c
Physcia adscendens (Fr.) H.Olivier	0	0	0	fo.na	A.s	c
Physcia caesia (Hoffm.) Fürnr. v. *caesia*	0	1	0	fo.na	A.s	r
Physcia dubia (Hoffm.) Lettau	1	0	0	fo.na	A.s	r (low alt)
Protoparmeliopsis bolcana (Pollini) ined.	1	0	1	cr	S	c
Protoparmeliopsis muralis (Schreb.) M.Choisy	1	1	1	cr	S	c
Ramalina capitata (Ach.) Nyl. v. *capitata*	1	1	0	fr	A.s	r
Ramalina capitata v. *digitellata* (Nyl.) Nimis	1	0	0	fr	A.s	r
Ramalina polymorpha (Lilj.) Ach.	1	1	0	fr	A.i	r (low alt)
Ramalina requienii (De Not.) Jatta	1	0	1	fr	A.s	r
Ramalina subfarinacea (Nyl. ex Cromb.) Nyl.	1	0	0	fr	A.s	r
Rhizocarpon geographicum (L.) DC.	1	0	1	cr	S	r (low alt)
Rinodina gennarii Bagl.	1	0	0	cr	S	c
Rinodina teichophila (Nyl.) Arnold	0	0	1	cr	S	c
Rinodina sp.	0	1	0	cr	S	n.a.
Tephromela atra (Huds.) Hafellner v. *atra*	1	1	0	cr	S	c
Xanthoparmelia loxodes (Nyl.) O.Blanco, A.Crespo, Elix, D.Hawksw. & Lumbsch	1	1	1	fo.br	A.s	c
Xanthoparmelia conspersa (Ach.) Hale	1	1	1	fo.br	A.i	r (low alt)
Xanthoparmelia pulla (Ach.) O.Blanco, A.Crespo, Elix, D.Hawksw. & Lumbsch	1	0	1	fo.br	S	c
Xanthoparmelia stenophylla (Ach.) Ahti & D.Hawksw.	1	0	1	fo.br	S	r
Xanthoria calcicola Oxner	1	1	1	fo.br	S	c
Tot.	33	18	20			

Notes: The presence/absence (1/0), growth form (cr, crustose; fo.br, foliose broad-lobed; fo.na, foliose narrow-lobed; fo.um, foliose umbilicate; fr, fruticose; lich.f., lichenicolous fungus), reproduction (S, mainly sexual; A.s, mainly asexual by soredia; A.i, mainly asexual by isidia) and rarity status (r, rare; c, common; r(low alt), rare at lower altitude; n.a., non available) are reported.

(62.5%) and 25% rare for Sardinia, whereas 12.5% are rare only at lower altitudes (Table I).

On the rock outcrops around the dolmen, 20 species were found. Most of them are crustose (60%), followed by broad-lobed foliose forms (30%), one (5%) fruticose species and one (5%) lichenicolous fungus. The majority of the species reproduce sexually (80%); only 10% of them reproduce asexually by soredia and 10% by isidia. Among the species found there, 73.6% are common or very common, 21.1% are rare and 5.3% are rare at lower elevations only (Table I).

Lichen cover and composition on the dolmen were variable at different exposures and light conditions. In the internal walls, lichen cover was low and dominated by crustose lichens, whereas the highest cover was found in the south-facing wall and in the capstone. The latter, in particular, was characterized by the presence of many fruticose, foliose (broad-lobed and narrow-lobed) and crustose lichens. The fruticose forms were also quite numerous in the north-exposed wall but less abundant. Fruticose, broad-lobed and narrow-lobed foliose thalli are also very common and abundant in the menhir and in the three stones near the dolmen. The rock outcrops instead have mainly crustose and foliose broad-lobed thalli, while only a fruticose thallus, of the species *Ramalina requienii*, was found.

The species found on dolmen, menhir and surrounding rocks are typical of sun-exposed areas and thus have a solar irradiation index between 3.5 and 4.5 (Figure 3).

The species found on dolmen, menhir and natural outcrops are mostly mesophytic (aridity index ranging between 3 and 3.5). The percentage of xerophytic species is higher on the menhir (25%) and natural outcrops (20%), whereas the dolmen has the highest percentage of rather hygrophytic species (21.2% on the total number of 33 species) (Figure 4).

Many species are also typical of anthropic environments: on the dolmen and natural outcrops, the majority of species has an eutrophication index ranging between 3 and 3.5, respectively 30.3% of the species on the dolmen and 40% of those found in the natural outcrops. The species with index between 4 and 4.5 are the most common on the menhir, and their percentage (37.5%) is high. On the contrary, if compared with menhir and natural outcrops, the dolmen has the highest percentage of species with very weak eutrophication (18.2% with an index ranging between 1 and 1.5) (Figure 5).

Discussion

The number of 33 lichen species found on the investigated dolmen indicates high diversity, especially when compared with the 6 and 12 epilithic species found, respectively, in the Tapadão dolmen and in the Zambujeiro dolmen (southern Portugal) (Romão & Rattazzi 1996). The higher percentage of

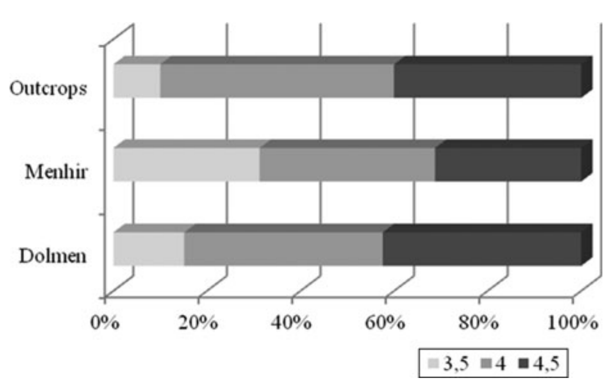

Figure 3. Percentage of lichen species on dolmen, menhir and natural outcrops divided according to their index of solar irradiation.

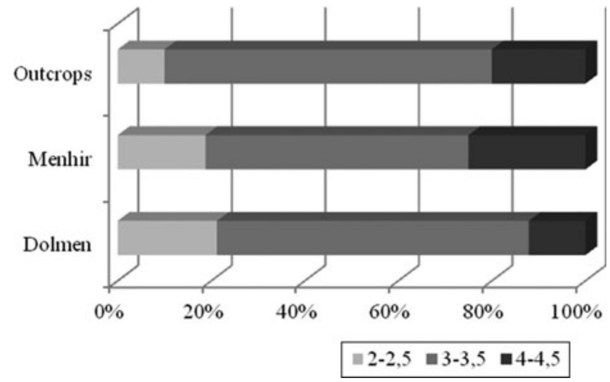

Figure 4. Percentage of lichen species on dolmen, menhir and natural outcrops divided according to their index of aridity.

rare species found on the dolmen rather than on the surrounding rocks indicates that this monument, with its particular and diverse micro-environments (vertical and horizontal stones with different exposure and illumination) was an important substrate for the survival of these species. Particularly, *Ramalina* species are most abundant on both monuments, and more diverse on the dolmen, but rare on the rock outcrops. Only a single thallus of *Ramalina* was found in the basement just near the dolmen, and rare species, such as *Ramalina capitata* and *Ramalina subfarinacea*, were not found on the native rocks. The variety and abundance of fruticose species found in the capstone (Figure 2(A)) and in the south-facing walls of the dolmen are not present in the surroundings, where mainly crustose and broad-lobed foliose lichens are found (Figure 2(C)). On the contrary, the menhir and the three stone fragments placed in proximity of the dolmen (Figure 2(B,D)) have a high frequency of fruticose thalli of *Ramalina*, in particular *Ramalina capitata* and *Ramalina polymorpha*. According to Basoli et al. (2011), also these parts of the megalithic monument are going to be treated in the same way as the dolmen. This means that lichens will be also

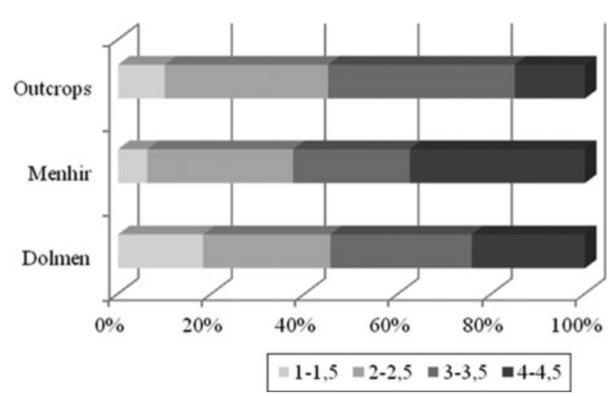

Figure 5. Percentage of lichen species on dolmen, menhir and natural outcrops divided according to their index of eutrophication.

destroyed from there. As the lithology of surrounding outcrops, dolmen, menhir and stones close to dolmen is the same, differences in lichen richness and composition are explained not only with differences in exposure, but also with the greater man-made disturbance (i.e. grazing) present around the megalithic complex.

Basoli et al. (2011) report that the monitoring of the structure of the dolmen before restoration had highlighted static problems to be related to weathering by water, wind and the biological crusts, present on the internal and external walls of the monument. As a matter of fact, the real role played by biogenic crusts in the weathering of the monument has not been analysed in detail, and the removal of lichen layers was carried out without consultation of lichenological expertise.

The lichen cover alone is not to be considered a valid parameter for quantifying biodeterioration. A series of careful standard investigations and analyses have to be carried out in order to evaluate physical and chemical lichen-stone interactions, i.e., direct optical or electron microscopic (SEM/EDS) observations, of rock-lichen undisturbed samples and stone sections, X-ray diffraction and IR spectroscopy (FT-IR) (Terribile et al. 2012). The species present and their growth forms are first parameters to be considered in such investigations, as deterioration effects are very different from species to species. Fruticose thalli, such as those of *Ramalina* spp. and of umbilicate (i.e. *Lasallia pustulata*) lichens are supposed not to be dangerous as they anchor to the substratum with a small part of the thallus only. No endolithic lichens were recorded, which are usually among the most bioactive groups in rock weathering. According to Seaward and Giacobini (1988), the biolithic crusts can persist for centuries without damaging rocky surfaces, and in several monuments, higher stone degradation has been observed in parts bare of lichens. As a matter of fact, the impact due to lichens can be in some cases even lower than the one caused by atmospheric agents, so that their removal and the loss of this protective layer can accelerate the erosion by wind and water.

Also valuable is the cultural value of lichens with their chromatic effects on nuragic and megalithic monuments. These have been part of the Sardinian landscape since centuries, and the name of such monuments often reflects the presence of lichens, i.e. several nuraghes are called Nuraghe Ruju (which means red nuraghe) for the occurrence of the orange-reddish thalli of *Caloplaca* and *Xanthoria* (Camarda 1992).

As demonstrated by different authors, if ecological conditions suitable for lichen growth are not eliminated during or after restoration, lichen removal has only temporally limited effect and lichens will recolonize the substratum in a short time. Some important parameters that could be modified for limiting lichen grow are for instance illumination, eutrophication and water availability (e.g. Nimis 2001; Nascimbene & Salvadori 2008; Nascimbene et al. 2009). Moreover, recolonization is performed by pioneer species, which might be different from those present on the monument in climax conditions. Pioneer species might have even more detrimental impact on the monument in comparison to those adapted to live on the monument for centuries (Nimis 2001; Nascimbene et al. 2009).

It is worth noting that historical buildings are surely a human heritage but also the biodiversity on them deserves to be preserved and many authors agree on the necessity to find a balance between the safeguard of archaeological and architectural heritages and nature protection (Rigamonti 2008).

At this stage, we cannot assess the effective need of lichen removal for preserving the dolmen of Coveccada or other megalithic monuments of Sardinia, but we wish to underline the importance of a closer and more effective collaboration between superintendents and lichenological experts, as already successfully experimented in other regions of Italy (Nimis et al. 1992). To deal appropriately with the problem, lichenologists should be consulted to evaluate the ecological importance of the lichen diversity on monuments and the effective role played by lichens in the biodeterioration of the substratum (Nimis et al. 1992; Salvadori & Tretiach 2002; Gazzano et al. 2009). This work puts the basis for later studies on lichens and nuragic and megalithic monuments in Sardinia, which are particularly abundant (about 8000 nuraghes), and it will be interesting to investigate the recolonization of the dolmen by lichens during the next years.

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