Sci. Rep. Port-Cros natl. Park, Fr., 24 : 185-196 (2010)

Field-methods to analyse the condition of Mediterranean *Lithophyllum byssoides* (Lamarck) Foslie rims

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Résumé. **Méthodes d'évaluation in situ de la vitalité des encorbellements méditerranéens à *Lithophyllum byssoides* (Lamarck) Foslie**. En Méditerranée occidentale, lorsque les conditions sont favorables, l'algue rouge calcifiée *Lithophyllum byssoides* (Lamarck) Foslie (Rhodophyta, Corallinales) constitue, à la partie inférieure du médiolittoral, d'importants bioconcrétionnements dénommés encorbellements ou "trottoirs" à *Lithophyllum byssoides*. Malgré un taux de croissance relativement fort pour une Corallinale encroûtante, la formation d'un encorbellement à *L. byssoides* avec une partie centrale consolidée est un long processus (plusieurs siècles). Les encorbellements à *L. byssoides* constituent donc de précieux indicateurs de la stabilité ou d'une lente remontée du niveau marin et d'une bonne qualité de l'eau sur de longues périodes. Jusqu'à présent, les programmes de surveillance de l'environnement prennent seulement en compte la répartition et le développement de *L. byssoides,* sans considérer sa vitalité. Nous présentons ici les méthodes de terrain simples d'évaluation de la vitalité des encorbellements à *L. byssoides* basées sur l'identification de la meilleure saison d'investigation (automne), la définition de différents états de vitalité de *L. byssoides* (vivant, mort, épiphyté, cassé ou érodé), et l'évaluation des pourcentages de couverture de surfaces mortes ou vivantes de *L. byssoides*.

Abstract. In the western Mediterranean Sea, under favourable environmental conditions, the red calcified alga *Lithophyllum byssoides* (Lamarck) Foslie (Rhodophyta, Corallinales) constitutes at the lower part of the mid-littoral large bioconstructions referred to as *Lithophyllum byssoides* rims or *L. byssoides* "trottoirs". In spite of the relatively high growth rate of *L. byssoides* when compared to other encrusting Corallinales, the development of a rim with a hardened core is a long process (several centuries). Consequently, the *L. byssoides* rims are valuable indicators of a near-stable or slowly rising sea-level and high sea-water quality over long periods. Hitherto, the environmental monitoring programmes have only taken into account the distribution and the development of *L. byssoides* without any attention to its condition. Here we propose easy field methods to analyse the condition of *L. byssoides* rims on the basis of the identification of the best study season (autumn), the definition of different conditions of *L. byssoides* (living, dead, epiphytized, broken or eroded) and the assessment of percent cover of living and dead *L. byssoides* surfaces.

INTRODUCTION

In the western Mediterranean Sea, under favourable environmental conditions, the red calcified alga *Lithophyllum byssoides* (Lamarck) Foslie (Rhodophyta, Corallinales) constitutes at the lower part of the mid-littoral large bioconstructions referred to as *Lithophyllum byssoides* rims (in French: "*Encorbellements ou corniches à L. byssoides"*, incorrectly named :"*trottoirs* à *L. byssoides* ") (Picard, 1954; Blanc and Molinier, 1955; Ballesteros, 1984; Laborel *et al.*, 1994a). These formations are the largest biogenic constructions in the Mediterranean Sea along with the Coralligenous assemblages (Laborel, 1987; Sartoretto *et al.* 1996). One of largest examples of *L. byssoides* rims occurs in the Scandola Nature Reserve in Corsica (Cala Litizia rim, Punta Palazzu) (Figs. 1 and 2). The internal organization of a *L. byssoides* rim is composed of three different parts: (i) a porous outer layer of living *L. byssoides,* a few centimetres deep, located on the upper and vertical surfaces of the rim, resting upon an unconsolidated layer of dead *L. byssoides*, (ii) an inner hardened multi-layered zone resulting from deposition processes filling-up the interstices between lamellae with a hardened sedimentary matrix, and (iii) a lower eroded surface that is dead and profusely colonized by subtidal organisms (Blanc and Molinier, 1955; Laborel, 1987).

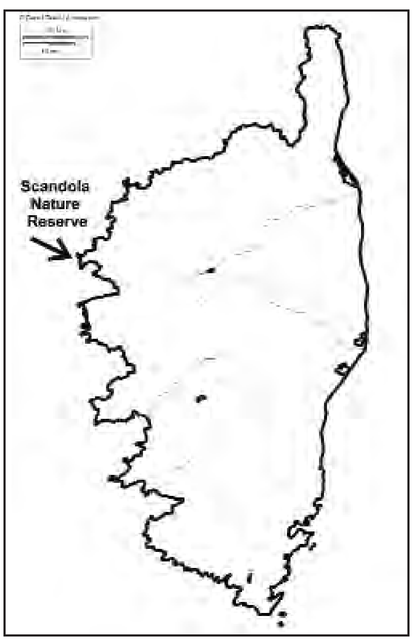


Figure 1. Corsica with the location of the Scandola Nature Reserve.

The growth of a *L. byssoides* rim only concerns the outer layer of living *L. byssoides*. In spite of the relatively high growth rate of *L.*

byssoides when compared to other encrusting Corallinales, the development of a rim with a hardened core is a long process (several centuries if not millennia). Radiocarbon datings have shown that the Cala Litizia rim was built between 1000-900 B.P. and the present (Laborel *et al.,* 1994b). *Lithophyllum byssoides* has a narrow vertical range and its mid-littoral location exposes it to sea-surface pollution. Consequently, *L. byssoides* rims are valuable indicators of near-stable or slowly rising sea-level and high sea-water quality over long periods (Laborel *et al.,* 1983, 1993b; Morhange *et al.*, 1993; Laborel and Laborel-Deguen, 1994; Morhange, 1994; Bressan *et al.*, 2001). Hitherto, the environmental monitoring programmes have only taken into account the distribution and the development of *L. byssoides* without any attention to its condition (Bianconi *et al.,* 1987; Janssens *et al.,* 1993; Blacher *et al.*, 1998; Mari *et al.*, 1998; Meinesz *et al.*, 2001; Cottalorda *et al.*, 2004). However, since the 1970s, deterioration of *Lithophyllum byssoides* rims has been reported in different western Mediterranean areas (Morhange *et al.*, 1992; Laborel *et al.*, 1993a and c) (Figs. 3 and 4). Since *L. byssoides* rims can persist a long time after the death of *L. byssoides*, efficient monitoring of *L. byssoides* rims needs to consider the condition of these biogenic constructions. Here we propose various simple field methods to analyse this parameter.

MATERIAL AND METHODS

The devising and testing of field methods was conducted in 1995 in the Scandola Nature Reserve (Corsica) where *L. byssoides* rims are common and well-developed. The aspect of *L. byssoides* changes throughout the year according to moistening by waves, temperature and sunshine. In winter, unfavourable weather conditions prevent field study. Conversely, in summer, the fine weather makes the *L. byssoides* rims more accessible but strong sunshine and high temperatures induce drying and bleaching of *L. byssoides,* so it becomes impossible to distinguish the living *L. byssoides* portions from dead portions. Consequently, two study periods were considered: spring and autumn. During both periods a large number of *L. byssoides* rims were studied, photographed and compared, with a special attention to the exceptional *L. byssoides* rim of Cala Litizia (Fig. 2). To highlight possible recent changes, previous data (Laborel *et al.*, 1984, 1993a-c, 1994b; Bianconi *et al*., 1987) and early photographs of the *L. byssoides* rims in Scandola Nature Reserve have been systematically searched for and analysed.

WHAT IS *LITHOPHYLLUM BYSSOIDES*?

Basionym: *Nullipora byssoides* Lamarck.

Currently accepted name: *Lithophyllum byssoides* (Lamarck) Foslie.

Synonyms: *Goniolithon byssoides* (Lamarck) Foslie, *Lithothamnion byssoides* (Lamarck) Philippi, *Titanoderma byssoides* (Lamarck) Y.M. Chamberlain & Woelkerling, *Lithophyllum lichenoides* Philippi and *Melobesia lichenoides* (Philippi) Endlicher.

Misapplied names: *Millepora tortuosa* Esper, *Lithophyllum tortuosum* (Esper) Foslie and *Tenarea tortuosa* (Esper) Lemoine.

Lithophyllum byssoides is a common mid-littoral, encrusting (non-geniculate) coralline alga, which occurs commonly in the Mediterranean and in NE Atlantic. It forms cushion-like clumps, (4-) 8 - 15 (-45) cm in diameter and 2 cm high that are composed of convoluted erect lamellae united into a complex, densely interweaving and anastomosing honeycomb-like mass (Figs. 5 and 6). The lamellae are up to 800 µm thick (Hamel and Lemoine, 1953; Bressan, 1974; Chamberlain, 1997; Bressan and Babbini, 2003). Under dim light and wet conditions, the living *L. byssoides* is dark pink to mauve in colour (Figs. 3 and 6). It becomes greyish-white and fragile when dried.

Lithophyllum byssoides has an isomorphic life history with alternation of gametophytes and tetrasporophyte. Gametangial plants are dioecious. The reproduction of tetrasporophyte has been observed at different periods depending on the authors and the locations: March-July at Marseilles (Huvé, 1956a and b), June-October in Portugal (Ardré, 1970) and February-December in the Balearic Islands (Gomez-Garreta, 1981). The reproduction of gametophytes has been only observed in autumn (October) (Chamberlain, 1997). According to Huvé (1954, 1970), the main period of recruitment is the autumn.

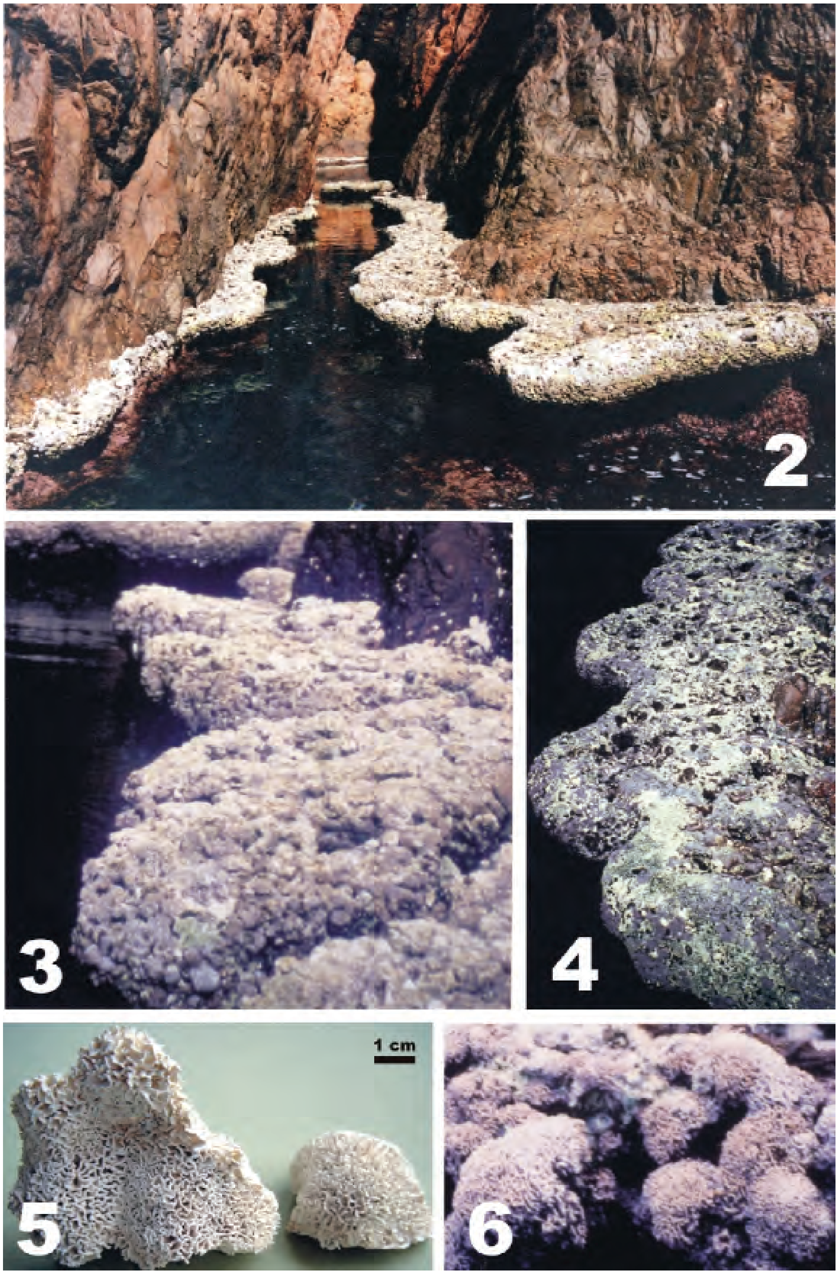
The growth rate of *L. byssoides* is relatively high when compared to other encrusting Corallinales.

A young *L. byssoides* can grow as much as 1.5 mm in height per month and reach 6 cm in diameter and 1.5 cm thick in three years (Huvé, 1956b; Boudouresque *et al.,* 1972). The species can reproduce from the first year (Huvé, 1956b).

After destruction, *L. byssoides* is able to quickly re-colonize the substratum. A nearly 100 % recovery of cleared colonies was observed after only two years (Huvé, 1954, 1956a and b; Laborel *et al.*, 1984). The recovery process can be aborted when the environmental conditions are altered (Morhange *et al.*, 1992; Laborel *et al.*, 1993c).

HOW TO ANALYSE THE CONDITION OF *LITHOPHYLLUM BYSSOIDES*?

The mid-littoral position of *Lithophyllum byssoides,* close to the sea-surface, exposes the species at once to atmospheric and marine pollution. In the north-western Mediterranean, a general deterioration of the living surface of *L. byssoides* rims due to the adverse effect of ever-increasing pollution of sea-surface water and their disappearance in the



Figures 2-4. The *Lithophyllum byssoides* rim of Cala Litizia (Punta Palazzu, Scandola Nature Reserve). **Figure 2.** General view (May 1995). **Figure 3.** Median part in 1976 or 1978 (healthy rim, Photo PNRC)**. Figure 4.** The same in October 1995 (altered rim). **Figure 5.** Macro-photography of healthy *L. byssoides* showing the erect lamellae. **Figure 6.** Macro-photography of living *L. byssoides* on a healthy rim.

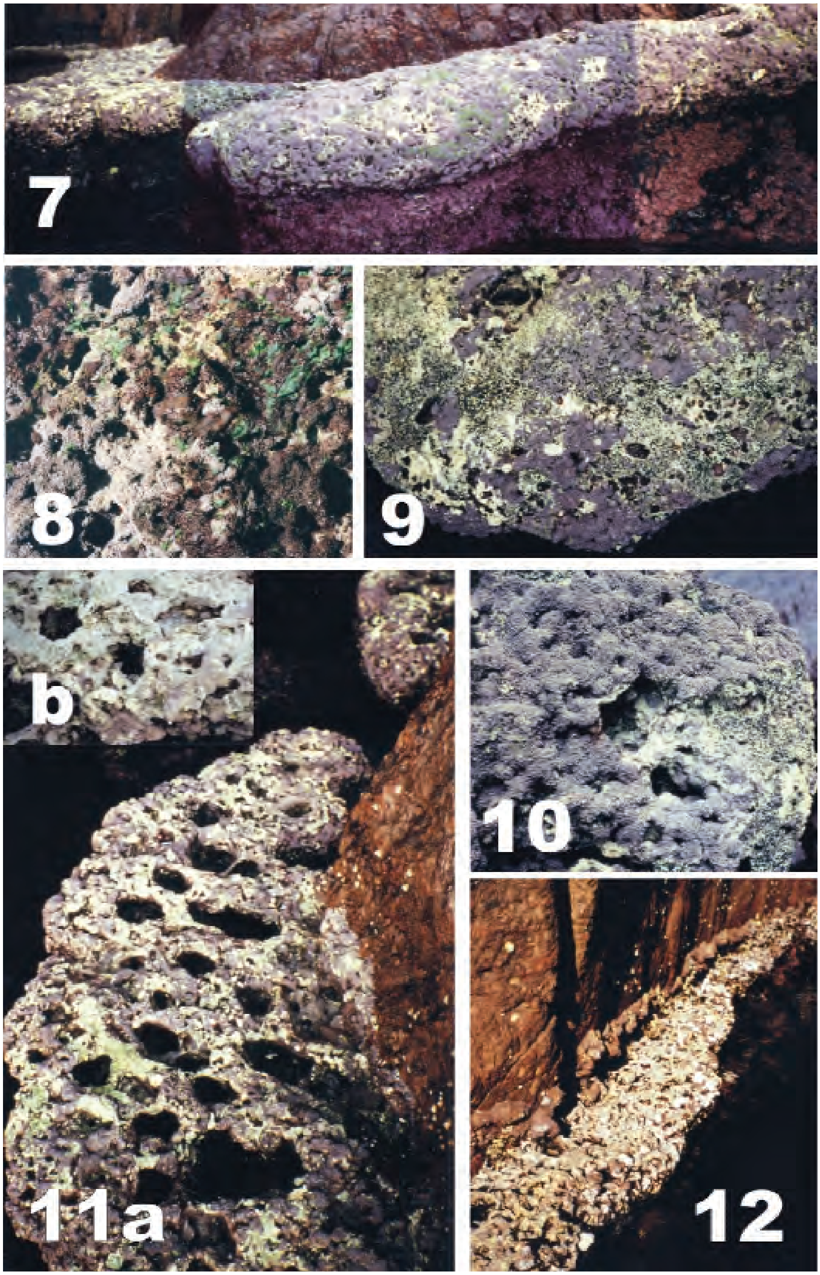


Figure 7. Frontal part of the Cala Litizia *L. byssoides* rim showing the juxtaposition of living (colourful) and dead (bleached) *L. byssoides* patches (Oct. 1995). **Figure 8.** Bleached *L. byssoides* rim colonized by various species of Rhodophyta and Chlorophyta (Cala Litizia, May 1995). **Figure 9.** Dead *L. byssoides* colonized by Cyanobacteria (*Rivularia* sp.) (Cala Litizia, Oct. 1995). **Figure 10.** Broken portion (Cala Litizia, Oct. 1995). **Figures 11a and b.** Highly eroded *L. byssoides* rim with blow holes (Cala Litizia, Oct. 1995); **b:** detail. **Figure 12.** *L. byssoides* level developed over a quasi-dead *L. byssoides* rim (Scandola Nature Reserve, Oct. 1995).

discharge area of urban outflows have been reported (PNUE/UICN/GIS Posidonie, 1990; Morhange *et al.*, 1992; Laborel *et al.,* 1993a and c). In the Scandola Nature Reserve as in the whole north-western Mediterranean, we have observed this deterioration of *L. byssoides* rims (Figs. 7-16). The dead patches of *L. byssoides* were profusely colonized by soft algae in spring (Fig. 9). The brittle surface of the living and dead unconsolidated *L. byssoides* layer was frequently broken or damaged by mechanical action (wrecks, boats, stalling) (Fig. 10). Locally, bioerosion by endolithic algae (Cyanobacteria and Chlorophyta), sponges (*Cliona*)*,* molluscs (*Lithophaga*) and echinoids (*Paracentrotus*) weakened the internal hardened core of *L. byssoides* rims by the formation of blow holes (Fig. 11). In a few localities of the Scandola Nature Reserve, we also observed the development of a new *L. byssoides* level above lower dead rims (Fig. 12). Similar upward displacements have been also observed at Marseille by Laborel *et al.* (1994b) who think that is consistent with the sea-level rise recorded during the 20th century.

To analyse the condition of *L. byssoides*, we have to distinguish the living portions, i.e. the cushion-like clumps of *L. byssoides* with colourful unbroken lamellae (Figs. 3, 6), from the different categories of injuries described above, i.e. bleached dead, epiphytized, broken and eroded *L. byssoides* (Figs. 8-11). A comparison of observations made in spring and autumn showed that, in spring, the discrimination between living and dead *L. byssoides* portions is hampered by the washed-out colour of living *L. byssoides* and the bloom of mid-littoral soft algae. Conversely, in autumn, the living cover of *L. byssoides* has a beautiful mauve colour and the soft algae are poorly developed, which makes it easier to distinguish between living and dead portions of rims (Fig. 7). Consequently, the best season to analyse the condition of the *L. byssoides* rims is the autumn and, as far as favourable climatic conditions are concerned, the best month is October.

HOW TO ANALYSE THE CONDITION OF *LITHOPHYLLUM BYSSOIDES* RIMS?

To analyse the condition of a *L. byssoides* rim, we have to only consider the growing parts of the rim, i.e. the upper side and, if necessary, the vertical side where *L. byssoides* is able to grow.

In ecology, to study modular organisms (e.g. coral colonies, encrusting organisms) that are too difficult to distinguish as individuals, percent cover is used in place of directs counts in order to save time and effort. Three quick and effective methods can be easily used: the photographic, the random quadrat and the random line transect methods.

The most simple method is photographic monitoring of selected zones that can be easily located by means of landmarks (fixed points:

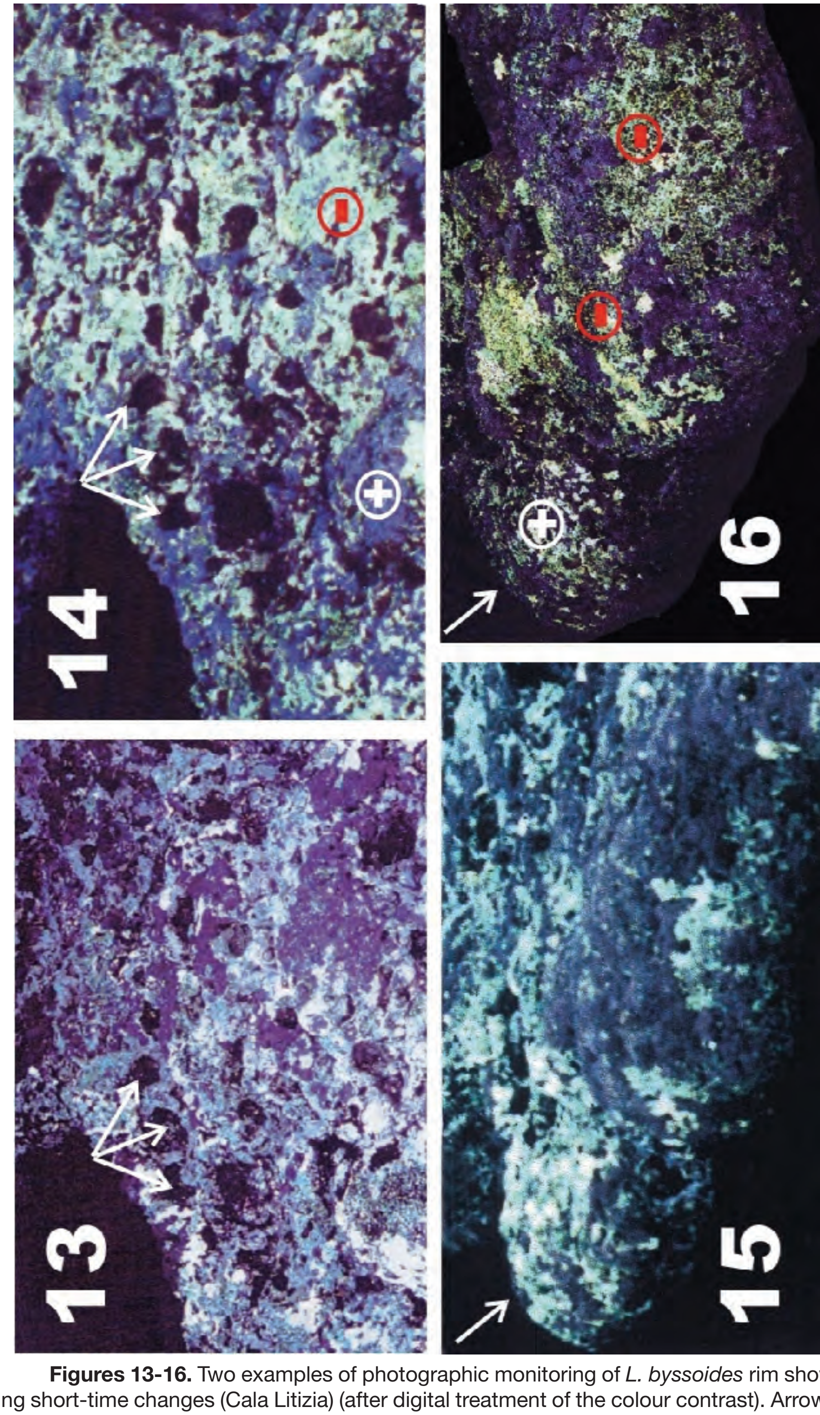
e.g. micro-relief, hollows, holes) or permanent markers. The analysis of pluriannual sets of photographs, each taken in October, allows identification of recent changes in the living *L. byssoides* cover (Figs. 13-16).The digitising of permanent or random quadrat photographs can be performed to quantify the living and dead surfaces. The colour contrast between living and dead *L. byssoides* patches can be enhanced by digital processing of images.

The two other methods are based on the point-intercept techniques. In the random quadrat method, a quadrat with a 100 intercepts-grid is randomly placed on the substratum and the percent cover of different items is given by the number of contacts of the item with the intercepts. In the case of *L. byssoides* rims, two categories must be considered : living and dead *L. byssoides.* To save time, the less frequent category must always be selected (i.e. dead *L. byssoides* on healthy rims and living *L. byssoides* on severely altered rims). When *L. byssoides* rims are too narrow, the random quadrat method is replaced by the random line transect method. A rod with 100 evenly spaced marks is randomly placed on the rim and the percent cover of different items is given by the number of contacts of the item with the marks. To allow statistical analysis, at least 30 quadrats or line transects per *L. byssoides* rim are required. Several different quadrats or line transects can be randomly sampled on the same surface. Contacts with small holes are classed as dead *L. byssoides* but the portions of *L. byssoides* rims with large blow holes must be avoided because such structures can be of natural origin. In the Scandola Nature Reserve, we tested with success the random quadrat method using a 20 cm X 20 cm or 40 cm X 40 cm quadrat according to the width of *L. byssoides* rims. For example, at Cala Litizia, the 95% confidence interval of the mean percent cover of dead surfaces (mean $\pm$ standard error) ranged from 35.8 - 46.0 % to 39.9 - 49.8 %, highlighting a dramatic alteration since the 1970s. For the random line transect method the use of a 100 cm or 50 cm rod is recommended.

CONCLUSION

Lithophyllum byssoides and the *L. byssoides* rims have been classed in the Appendix II (List of endangered or threatened species) of the Bern Convention on the Conservation of European Wildlife and Natural Habitats (Council of Europe, 1979), and the Natura 2000[1] Mediterranean Marine Habitats requiring special protection, respectively. Moreover *Lithophyllum byssoides* rims have been selected as bio-indicator of a high environmental quality in the framework of the

[1]Natura 2000 is the European network of nature protection areas (Council Directive 92/43/EEC).



Figures 13-16. Two examples of photographic monitoring of *L. byssoides* rim showing short-time changes (Cala Litizia) (after digital treatment of the colour contrast). Arrows: fixed points; **+**: newly re-colonized surfaces; **-** : newly dead surfaces. **Figures 13 and 15.** September 1992 (Photo J. Laborel). **Figures 14 and 16.** October 1995.

European Water Framework Directive (WFD, 2000/60/EC) (Ballesteros *et al.*, 2007). Nevertheless no method to estimate the condition of *L. byssoides* rims has hitherto been proposed. As far as the global climatic change is concerned, Mediterranean *L. byssoides* rims will not be successful in coping with a too rapid rise of the sea-level (Laborel *et al.* 1994), and the biogenic constructions will be condemned. However, in the absence of sea-surface pollution, the species should be able to grow higher up on the substratum. Consequently there is an urgent need to implement quantitative monitoring of *L. byssoides* rims.

Here we propose three simple field methods (photographic, random quadrat and random line transect methods) to implement in autumn (October) when the living *L. byssoides* cover is colourful and the soft algae cover is scarce. The photographic method seems to be the simplest monitoring method for small *L. byssoides* rims, whereas the random quadrat and the random line transect methods are more to be recommended for larger *L. byssoides* rims.

Acknowledgements. We would like to thank the *"Parc Naturel Régional de Corse"* (PNRC), Profs Jacques Laborel and Alexandre Meinesz, and Mrs Françoise Laborel-Deguen for sending photographs of *L. byssoides* rims, MM. Jean-Marie Dominici and François Arrighi of the PNRC for field work assistance, Michèle Perret-Boudouresque for bibliographical assistance and Michael Paul for reviewing the English text. The study was supported by a grant from the *"Parc Naturel Régional de Corse"*.

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