Mapping of *Posidonia oceanica* beds around Elba Island (western Mediterranean) with integration of direct and indirect methods

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Abstract – Direct and indirect methods were used for mapping *Posidonia oceanica* beds around Elba Island. Side scan sonar and a visual infra red scanner were used to detect the extension of beds. Also, direct observations were adopted to assess the bed density and to calibrate the indirect methods. Samples of *P. oceanica* were collected and phenological variables and macroalgal epiphytes were studied to assess the health of the beds. *P. oceanica* around Elba Island covered an area of 3 680 ha. The largest beds occupied the four main gulfs of the island, characterized by gentle slopes and sandy bottoms. There, the beds showed uniform cover while a patchy structure was common on the rocky and steep bottoms of the western and south-eastern coasts of the island. *P. oceanica* beds at Elba Island demonstrated a good state of health. The epiphytic algal assemblage of the leaves was dominated by species generally found on this habitat, while, on the rhizomes, we observed a high covering of turf-forming species. The methods adopted allowed accurate maps at a scale of 1:10 000. The integration of data obtained both by direct and indirect methods and the precision of the positioning system were particularly important.

***Posidonia oceanica* / seagrass / algae / mapping / airborne teledetection / Mediterranean**

Résumé – Cartographie des herbiers à *Posidonia oceanica* de l'île d'Elbe (Méditerranée occidentale) par intégration de méthodes directes et indirectes. Le sonar latéral et la télédétection aérienne ont été utilisés pour la localisation des herbiers, tandis que des observations directes en plongée autonome et au moyen de véhicules sous-marins l'ont été pour identifier certaines images ou pour mesurer la densité des herbiers. Des faisceaux de *P. oceanica* ont été prélevés pour l'étude de la phénologie de la plante et de la communauté macroalgale épiphyte, de manière à évaluer la condition écologique des herbiers. *P. oceanica* autour de l'île d'Elbe couvre une surface de 3 680 ha. La pente limite l'expansion des herbiers, d'où une étendue très basse par rapport à la longeur de la côte (25,3 ha km^{-1}). Les herbiers les plus étendus apparaissent dans les baies principales de l'île : Campo, Lacona, Stella et Procchio. Les herbiers y présentent une couverture uniforme, tandis qu'une structure en taches est commune sur les fonds rocheux et à pente forte, le long des côtes occidentales et sud-orientales. Les paramètres structuraux et phénologiques traduisent une bonne condition écologique des herbiers à *P. oceanica*. De petites aires de régression sont présentes autour des ports principaux et le long de la côte nord-orientale, où les effets d'anciennes mines sont encore visibles. Les méthodes utilisées ont permis la réalisation de cartes très précises à une échelle de 1:10 000. L'intégration des données directes et indirectes et la précison du système de positionnement (DGPS) ont été particulièrement importantes pour la connaissance de l'étendue des herbiers et de leurs situation écologique. Ces résultats constituent un document pour la gestion du système littoral de l'île d'Elbe.

***Posidonia oceanica* / algues / cartographie / sonar latéral / télédétection aérienne / Méditerranée**

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1. INTRODUCTION

Cartography of the sea bottom plays a key role in coastal management. Knowledge of the distribution of the main marine biocenoses is of fundamental importance in conservation and monitoring programs. Sea bottom surveys have often involved mapping of seagrasses [7, 12, 14, 19, 26, 28, 43]. Seagrass beds are among the most important benthic communities in temperate coastal areas, where they have a fundamental ecological role. They produce organic matter, maintain the sedimentary equilibrium and protect sandy shores from erosion [15, 22, 27, 30]. The regression of seagrass beds observed throughout the world and caused by increasing pollution [42] needs accurate monitoring.

The knowledge of the extension of a bed and the definition of its limits must be considered as only part of the information necessary to manage this resource. It is very important to acquire data on some structural (density) and phenological characteristics which are indicators of the health of the beds and plants respectively [24, 25]. Also, of interest is the epiphytic community that can give information on the whole system (possible stress can be detected on the epiphytic community before seagrass is damaged) [16, 29].

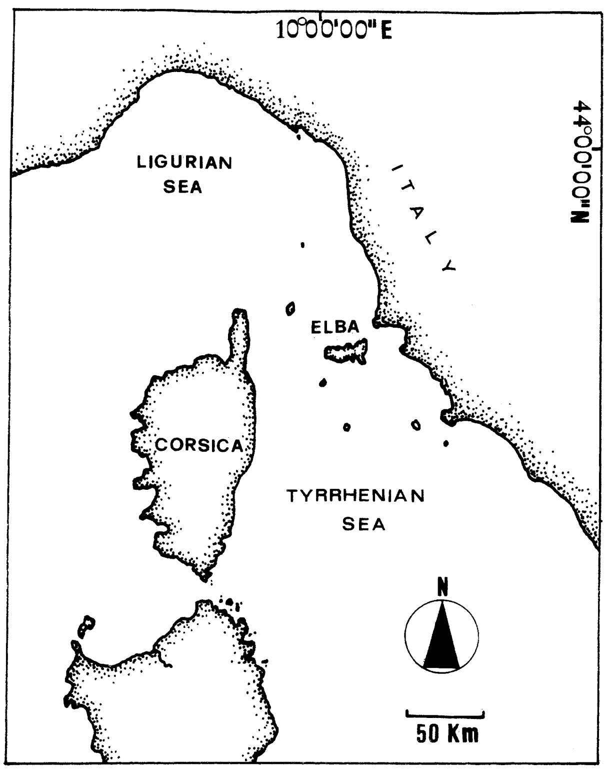

Fig. 1. Location of Elba Island.

In the Mediterranean Sea, mapping programs have been carried out to detect the distribution of the endemic marine phanerogam *Posidonia oceanica* (L.) Delile, widely distributed in a depth range from 0 to 40 m. The aim of this work was to implement protective measures and to evaluate the resources to be managed.

Underwater inspections by scuba diving were made in restricted areas [3, 13, 21, 23, 31, 38, 40] while indirect methods were employed in large scale mapping programs. Among the different methods used to map *P. oceanica*, side scan sonar [9, 17, 18, 20, 32, 37] was demonstrated to be the best instrument to map the lower limits of the meadows while aerial photographs [13, 33] and satellite images [8, 37] appeared to be techniques particularly suitable for the shallower layer. Thus, the best results have been obtained with the integration of several methods, chosen on the basis of the characteristics of the area, the maximum depth to be reached and the precision required [5, 6, 10, 34, 37].

In this study we present the results of a mapping program of the *P. oceanica* beds around Elba Island (Italy), realised using both direct and indirect methods. We examine the potential of the techniques adopted, discuss the results in relation to other Mediterranean coasts and give information on the health of the beds.

2. MATERIALS AND METHODS

Elba is the largest island of the Tuscan Archipelago (Western Mediterranean, Italy) (*figure 1*), with a surface area of 223.5 km^2 and a coast 147 km long.

Mapping of *Posidonia oceanica* meadows was carried out from April to July 1995. Side scan sonar (hereafter SSS) was used to discriminate *P. oceanica* beds from rocky and sandy bottoms. We used two recorders (graphic and digital) and a 'fish' bearing two transducers transmitting an acoustic signal at a frequency variable from 100 to 500 kHz. The return

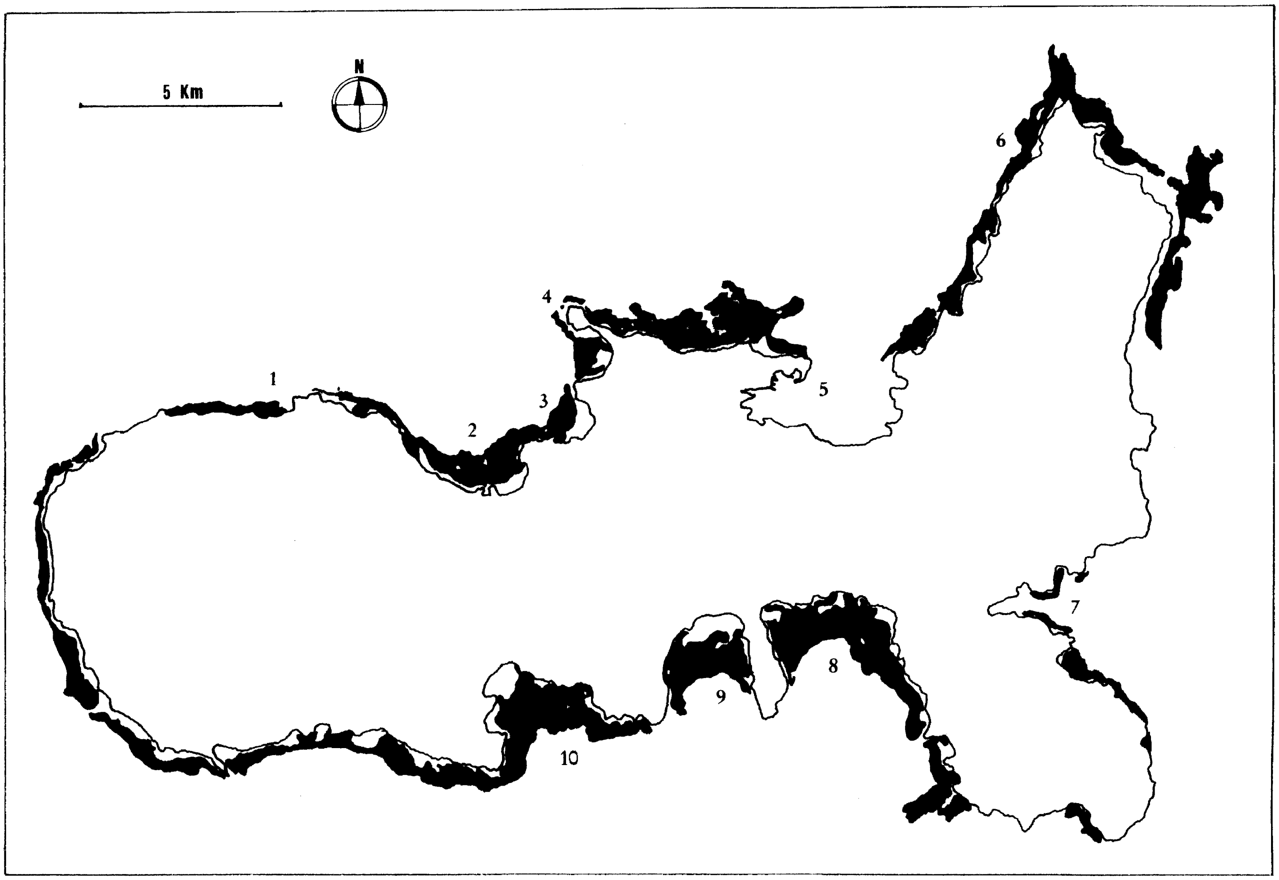

Fig. 2. Distribution of *Posidonia oceanica* beds (in black) around Elba Island. Numbers indicate the following localities. 1: Nasuto Cape; 2: Gulf of Procchio; 3: Gulf of Viticcio; 4: Enfola Cape; 5: Portoferraio; 6: Inferno Bay; 7: Portoazzurro; 8: Gulf of Stella; 9: Gulf of Lacona; 10: Gulf of Campo.

signal was picked up by the 'fish' and transmitted to the recorders on board ship. The 'fish' was dragged at a maximal speed of 5 knots (9.26 km h^{-1}). The ship's position was determined by a differential global positioning system (DGPS Trimble, precision $\pm$ 1 m). The data of SSS were real time interfaced with the positioning system using the Trimble hydro software. The SSS was used at a frequency of 100 kHz, covering a 200-m-wide band of sea bottom (100 m for each side). Sonograms at 500 kHz were prepared when a higher resolution was necessary. Navigation lines ran parallel to the coast 150 m apart, in order to allow sonograms to overlap. Some lines perpendicular to the coast were also made.

Airborne teledetection was obtained from the visible infrared scanner 201 (VIRS 201) in September 1994 and in April 1995. The VIRS is a multi-spectral imaging radiometer bearing two separate sensors acquiring data in the visible, near infrared (400–1 000 nm) and thermic infrared (8–12 nm) wave lengths. The number 201 indicates the possibility to detect 20 bands in the VIS- near infrared and one in the thermic infrared.

The image built is a line scanner type; the instrument is able to acquire wide areas through a succession of narrow bands perpendicular to the fly direction. Data are recorded and then analysed by dedicated software for PC.

Direct observations by scuba diving and remote operated vehicle were used to calibrate indirect methods. From the maps we calculated the surface area (ha) of *Posidonia oceanica* beds and the R_1 index equal to the seagrass bottom cover per kilometre of coastline [35].

Moreover, information on the health of the beds was obtained through the study of structural and phenological variables of the beds and of epiphytic flora. This study was carried out in July 1995 at three localities (Inferno Bay, Nasuto Cape, Gulf of Viticcio) (*figure 2*) randomly chosen from a set of all the possible localities around the island. Shoot density was assessed in five 0.1 m^2 samples collected by scuba diving at depths ranging from 10 to 20 m. At each locality ten shoots were sampled and, in the laboratory, the following phenological variables were calculated: mean number of leaves, mean leaf length per shoot and Leaf Area Index (mean leaf surface per shoot/2 $\times$ mean shoot density) [24, 25, 36]. Macroalgal epiphytes of leaves and rhizomes were identified in the laboratory using a binocular microscope.

3. RESULTS

Seven bionomic maps and seven bathymetric maps at a scale of 1:10 000 were realised (available at *Dipartimento di Scienze dell'Uomo e dell'Ambiente*, University of Pisa). *Posidonia oceanica* stands showed a continuous distribution along the coast of Elba Island (*figure 2*). The total surface colonised by the seagrass at Elba Island was 3 680 ha, and R_1 was 25.03 ha km^{-1}. The distribution of the seagrass was affected by the morphology of the bottom. The largest beds were in the main gulfs of the Island: Procchio at the north-side, Campo, Lacona and Stella at the south-side. Wide beds were also found between Enfola Cape and Portoferraio and in the north-eastern part of the island. Upper limits occurred at depths ranging between 3 and 10 m, while lower limits were localised between 30 and 40 m.

P. oceanica often colonised rocky bottoms, in particular along the western, north-western and south-eastern coasts of Elba, where meadows showed a patchy distribution. Plants showed a uniform cover on the sandy bottoms present in the main gulfs, where wide matte structures were also found. Meadows showed eroded edges along north-eastern and south-western coasts and restricted damaged areas near Rio Marina and in the Bays of Portoferraio and Porto Azzurro (*figure 2*).

The shoot density in the studied beds ranged from 500 ± 55 to 675 ± 95 shoots m^{-2}. Leaf Area Index varied from 8.4 ± 0.1 to 18.6 ± 9.5. The mean number of leaves ranged between 4.8 ± 0.3 and 6.2 ± 0.5 leaves/shoot while the mean leaf length between 40.8 ± 9.9 and 62.5 ± 4.2 cm (*table I*).

Twenty-eight macroalgal species were found on leaves (1 Chlorophyta, 9 Fucophyceae, 18 Rhodophyta) and fifty-one on rhizomes (10 Chlorophyta, 7 Fucophyceae, 34 Rhodophyta) (*table II*). Macroalgal assemblages on leaves were dominated by the encrusting Corallinaceae *Hydrolithon farinosum* (Lamouroux) Penrose and Chamberlain, *H. cruciatum* (Bressan) Chamberlain and *Pneophyllum fragile* Kützing and by the Fucophycea *Myronema orbiculare* J. Agardh. On the rhizomes the most abundant species were the Rhodophyta *Acrothamnion preissii* (Sonder) Wollaston, *Womersleyella setacea* (Hollenberg) R.E. Norris and *Peyssonnelia* spp.

4. DISCUSSION AND CONCLUSIONS

The distribution of *Posidonia oceanica* beds around Elba Island was strictly linked to the morphology of the bottom. A steep slope often limited the extension of the beds explaining a low value of the seagrass bottom cover compared to the length of the coastline (25.03 ha·km^{-1}) (*table III*). Despite the short distance from the mainland, Elba meadows appeared more similar to those of other islands of the Tuscan Archipelago [18] than to the meadows occurring along the continental coasts. In fact, the surface area

Table I. Structural and phenological variables of *Posidonia oceanica* measured in three different locations of Elba Island.

	Inferno Bay	**Nasuto Cape**	**Gulf of Viticcio**
Density (shoot·m^{-2})	500 ± 55	675 ± 95	613 ± 60
Mean number of leaves per shoot	6.4 ± 0.2	6.2 ± 0.5	4.8 ± 0.3
Mean leaf length per shoot	40.8 ± 9.9	62.5 ± 4.2	55.2 ± 5.2
Leaf area index	8.4 ± 0.1	18.6 ± 9.5	16.2 ± 2.8

Table II. Floristic list of macroalgal epiphytes of *Posidonia oceanica*.

Taxa	Leaves	Rhizomes
CHLOROPHYTA		
Chaetomorpha mediterranea (Kützing) Kützing		+
Cladophora albida (Nees) Kützing	+	+
Cladophora coelotrix Kützing		+
Cladophora echinus (Biasoletto) Kützing		+
Cladophora prolifera (Roth) Kützing		+
Cladohora vagabunda (Linnaeus) Hoek		+
Flabellia petiolata (Turra) Nizamuddin		+
Pseudochlorodesmis furcellata (Zanardini) Børgesen		+
Valonia macrophysa Kützing		+
Valonia utricularis Kützing		+
FUCOPHYCEAE		
Arthrocladia villosa (Hudson) Duby		+
Asperococcus compressus Griffiths *ex* Hooker	+	
Cladosiphon cylindricus (Sauvageau) Kylin	+	+
Dictyopteris polypodioides (De Candolle) Lamouroux		+
Dictyota linearis (C. Agardh) Greville	+	+
Feldmannia caespitula (J. Agardh) Knoeppfler-Péguy	+	
Giraudia sphacelarioides Derbés et Solier	+	
Halopteris filicina (Grateloup) Kützing		+
Myriactula gracilis Van der Ben	+	
Myriactula rivulariae (Suhr) J. Feldmann	+	+
Myrionema orbiculare J. Agardh	+	
Sphacelaria cirrosa (Roth) C. Agardh	+	+
RHODOPHYTA		
Acrosorium venulosum (Zanardini) Kylin		+
Acrothamnion preissii (Sonder) Wollaston	+	+
Anthithamnion cruciatum (C. Agardh) Nägeli		+
Anthithamnion ogdeniae Abbott		+
Apoglossum gregarium (Dawson) Wynne		+
Asparagopsis armata Harvey (sporophyte)		+
Botryocladia boergesenii J. Feldmann		+
Ceramium codii (Richards) G. Feldmann		+
Ceramium diaphanum (Lighfoot) Roth	+	+
Ceramium flaccidum (Kützing) Ardissone	+	
Chondria mairei G. Feldmann	+	
Crouania attenuata (C. Agardh) J. Agardh		+
Dasya corymbifera J. Agardh		+
Dasya ocellata (Grateloup) Harvey	+	
Erythrotrichia carnea (Dillwyn) J. Agardh	+	+
Eupogodon spinellus (C. Agardh) Kützing		+
Feldmannophycus raissiae (J. et G. Feldmann) Augier et Boudouresque		+
Halopitys incurvus (Hudson) Batters		+
Herposiphonia secunda (C. Agardh) Ambronn	+	+
Heterosiphonia crispella (C. Agardh) Wynne		+
Hydrolithon cruciatum (Bressan) Chamberlain	+	
Hydrolithon farinosum (Lamouroux) Penrose et Chamberlain	+	
Hypoglossum hypoglossoides (Stackhouse) Collins et Harvey		+
Jania rubens Lamouroux		+
Laurencia obtusa (Hudson) Lamouroux		+
Lomentaria chylocladiella Funk	+	
Monosporus pedicellatus (Smith) Solier		+
Peyssonnelia bornetii Boudouresque et Denizot		+
Peyssonnelia rubra (Greville) J. Agardh		+
Plenosporium borreri (Smith) Nägeli	+	
Plocamium cartilagineum (Linnaeus) Dixon		+
Pneophyllum fragile Kützing	+	
Polysiphonia furcellata (C. Agardh) Harvey		+
Polysiphonia scopulorum (Harvey) Womersley	+	+
Polysiphonia subulifera (C. Agardh) Harvey	+	+
Pterothamnion plumula (Ellis) Nägeli		+
Ptilothamnion pluma (Dillwyn) Thuret		+
Rhodophyllis divaricata (Stackhouse) Papenfuss		+
Seirospora sphaerospora J. Feldmann	+	+
Spermothamnion flabellatum Bornet	+	
Spyridia filamentosa (Wulfen) Harvey		+
Stylonema alsidii (Zanardini) Drew	+	+
Womersleyella setacea (Hollenberg) R.E. Norris	+	+

(ha) occupied by *P. oceanica* along these coasts was much larger than that occupied along the coasts of the islands (*table III*). Moreover, the continental meadows showed large damaged areas produced by anthropic activities and densities of leaves were generally low [17]. On the contrary, as observed for the other islands [18], structural and phenological variables demonstrate that Elba seagrass meadows are healthy. Nevertheless, restricted areas of regression were found close to the main harbours and along the

Table III. Surface area (ha) of *Posidonia oceanica* beds in different zones of the north-western coasts of Italy.

Reference	Zone	Surface area (ha)	Coastline length (km)	Surface area per km of coastline (ha·km^{-1})
Present study	Elba Island	3 680	147	25.03
Cinelli and Piazzi, 1990	Tuscany	20 277	300	67.59
Cinelli et al., 1995	Tuscan Archipelago	5 043	125	40.34
Bianchi and Peirano, 1995	Liguria	4 800	332	14.46

north-eastern coast of Elba where the effects of ancient mine activity are still visible. This points to the sensitivity of *P. oceanica* to human activities and is why it is regarded as a good biological indicator of water quality of coastal Mediterranean areas [39].

The epiphytic algal assemblage of the leaves was dominated by species generally found in this habitat. While, on the rhizomes, it was characterized by a high covering of the introduced Rhodophyta *Acrothamnion preissii* and *Womersleyella setacea*. The development of these turf-forming species changed the structure of the population of epiphytes, with a decrease in the number of species. This phenomenon was described in the other islands of the Tuscan Archipelago [41] and along the continental coasts of Tuscany [2].

The declaration of a marine national park in Elba Island requires a detailed knowledge of the distribution of marine biocenoses [4, 23]. The maps obtained should be a basis for monitoring of *P. oceanica* beds and a fundamental tool for administrators and decision makers. In particular, data about the extension of beds and their current state of conservation should contribute to adequate coastal management. These objectives can be obtained through an extremely precise cartographic representation at an adequate scale. The methods used in this work revealed a high efficiency that relied upon the integration of data obtained by different methods and the precision of the positioning system. The use of VIRS 201 gave good results, providing a fast acquisition of upper limits of the beds. At the moment, side scan sonar is the best method for large scale acquisition of the extent of the beds and of their deep limits. Moreover, recent studies have suggested the possibility of detecting information about structural and phenological variables [1, 11].

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