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Long-term change in the structure of a *Posidonia oceanica* landscape and its reference for a monitoring plan

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Abstract On the basis of a detailed cartographic survey carried out by Side Scan Sonar and a towed underwater video camera during 2005, and from a series of historical maps (1959, 1980, 1990), an extensive regression of *Posidonia oceanica* (L.) Delile beds was evidenced for a vast area of the central Tyrrhenian Sea (Latium coast, Italy). The total loss of *P. oceanica* surface was assessed through GIS estimate. In 1959, the *Posidonia* beds extended over 7290 ha, while in the 2005 survey they had regressed to 2899 ha, a loss of about 60% of their coverage. Also the seagrass lower limit showed a general depth decrease in time. Total seagrass coverage loss and lower limit regression were not uniform along the whole investigated areas and three main sub-areas have been identified with different degrees of regression somehow related with coastal potential human-mediated impacts. From different coverage estimates of the present survey and of the previous maps, minimum sampling areas were calculated through bootstrapping simulation routines from small sampling areas (Landscape Units) to reach the nearest estimate of the observed condition in the different periods.

Problem

Several studies have documented important regression trends for many seagrasses along most of the world's coasts (Walker & McCombe 1992; Marbà *et al.* 1996; Short & Wyllie-Echeveria 1996; Hemminga & Duarte 2000; Duarte 2002). Pollution, in its broadest sense of man-induced disturbance of the coastal marine environment, is recognized as the main source of perturbation with local direct and indirect impacts which may have an effect on the seagrass condition far away from the source of disturbance (Boudouresque *et al.* 2006).

Posidonia oceanica, a well studied seagrass in the Mediterranean Sea, is considered a key species because of its vast distribution along the infralittoral bottoms (Pérès & Picard 1964).

Important problems of regression for *Posidonia* beds have been reported and different sources of impact, such as coastal development (Pérès & Picard 1972; Meinesz *et al.* 1991; Pasqualini *et al.* 1999; Ruiz & Romero 2003), industrial sewage and urban discharge (Bourcier 1989; Pergent-Martini & Pergent 1995, 1996; Balestri *et al.* 2004; Boudouresque 2004), trawl fishing (Ardizzone & Pelusi 1984; Sanchez-Lizaso *et al.* 1990; Sanchez-Jerez & Ramon-Esplà 1996; Ardizzone *et al.* 2000), and fish farms (Delgado *et al.* 1997, 1999; Ruiz *et al.* 2001) have been described. In addition, there are marine operations which have caused negative impacts on seagrass beds such as boat anchoring (Garcia-Charton *et al.* 1993; Francour *et al.* 1999) and dredge operations (Guidetti & Fabiano 2000; Short & Coles 2001; Gambi *et al.* 2005; Badalamenti *et al.* 2006). Other authors report about natural causes of *Posidonia* beds regression (Gallegos *et al.* 1993; Marbà & Duarte 1994, 1997). On the contrary, other studies do not report significant loss of a *Posidonia* bed in the last years in a bay with a variety of human activities (Leriche *et al.* 2006).

Three main factors of disturbance can be identified among different sources of potential environmental modifications:

1 reduction of light penetration in the water column due to increased primary production, induced by eutrophic load in the coastal waters, and because of suspended inorganic sediments;
2 mechanical direct damage from fishing activity such as trawling, dragging and anchoring in the nearby coastal waters, particularly in recreational areas;
3 change in the sediment quality of the sea bottom, mainly from well sorted fine sand to silt, due to inputs coming from modification and building up of the coastline.

All these sources of disturbance have markedly increased during the last 50 years because of the rapid growth of human settlement along the Mediterranean coastline, where the resident population is doubling every thirty years and the tourist presence every 15 years (UNEP 1989, 1996). Much information is available on the sources of impact and their effect on seagrass meadows, and different studies have described quantitatively the spatial modification of *Posidonia* beds (Leriche *et al.* 2004; Boudouresque *et al.* 2006). Such information could be helpful in evaluating significant trends to be generalized at a landscape scale for regional assessment (Borum *et al.* 2004).

International conventions, EU regulations and national legislation protect *Posidonia* beds, try to limit any dangerous activity (Relini 1999), but an important obstacle to the formulation of conservation policies is the scarcity of information on the loss rate of seagrass beds due to the scarcity of monitoring programmes. Many projects of seagrass coverage cartography have been carried out in many Mediterranean countries and almost all the *Posidonia* beds along the coasts of Spain, France and Italy are known, but few monitoring programmes and estimates of loss rates of seagrass are available (Procaccini *et al.* 2003). Since 1990, for example, the Italian Ministry of the Environment has been funding surveys for many millions of Euro to know the extension of the *Posidonia* beds along all the Italian coasts (Liguria, Tuscany, Latium, Apulia in the 1989–1991 and, again, 2001–2003, Sicily and Sardinia in the 1999–2002, Campania and Calabria in the 2002–2004), and nowadays the whole national distribution is well known (Ministero dell'Ambiente e del Territorio 2003). This information constitutes an important starting point but it cannot give an estimate of the regression rate. The actual condition is therefore that few specific research studies on modification of spatial distribution of *Posidonia* beds have been carried out.

The lack of old historical references and the high costs of new surveys in areas where these data have been collected in recent years prevent any regular vast-area monitoring programme. Nevertheless, the critical conservation status of the *Posidonia* beds along the Italian coasts is by now a matter of general concern.

How, then, can we understand which is the trend of a *Posidonia* landscape modification at a reasonable macroscale? The first step is to map the distribution of *Posidonia* beds with a good level of accuracy for relatively large areas; the second (if available) is to evaluate reliable historical maps, and the third is to set up a monitoring system, trying to minimize the costs of these expensive surveys over large areas through a partial sampling of the area to be monitored. While the spatial pattern of terrestrial communities has been studied in depth by landscape ecologists (Forman & Gordon 1986; Turner 1989), little experience is at the moment available for the marine environment and particularly for benthic species, which are especially suitable for this approach (Garrabou *et al.* 1998; Kendrick *et al.* 1999). The temporal evolution of the spatial pattern of seagrass beds seems to be an interesting subject for the landscape ecology approach and a GIS application in this broad context will prove to be a fundamental tool (Lathrop & Bognar 1998; Zharikov *et al.* 2005). To map *P. oceanica* beds in the Mediterranean Sea different methods have been used. We only remember the use of underwater inspections by SCUBA diving (Gili & Ros 1985; Falconetti & Meinesz 1989; Ballesta *et al.* 2000), aerial photography (Pasqualini *et al.* 1998, 2001; De Falco *et al.* 2000), Side Scan Sonar (SSS) (Meinesz & Laurent 1978; Colantoni *et al.* 1982; Cinelli *et al.* 1995; Pasqualini *et al.* 1998), underwater videography (Ardizzone 1991; Norris *et al.* 1997; Bianchi *et al.* 2003), and the integration between these methods (Piazzi *et al.* 2000; Brown *et al.* 2002; Montefalcone *et al.* 2006). In particular, towed underwater videocameras have been used to map *Caulerpa prolifera* beds along the French coasts (Meinesz *et al.* 2001) and coral reef in tropical waters (Carleton & Done 1995; Miller 1999). A complete review of *P. oceanica* beds data acquisition and an application of the comparison of ancient *Posidonia* maps are in Leriche *et al.* (2004).

The aims of this paper were to evaluate the present coverage of large *P. oceanica* beds off the coast of Latium (Tyrrhenian Sea, Italy), to compare this condition with three historical maps dating back over fifty years, and to calculate through bootstrapping simulations the optimal confidence limits to obtain the percentage of sea bottom to be assessed (minimum sampling area) to understand the change in relation to known reference conditions.

Study area

This research was funded by the Latium Regional Administration to obtain an updated map of the *Posidonia* beds to be utilized as reference data during reclamation activities on the local beaches that will be operative in the coming future (Regione Lazio 2004).

The study area is located in the central Tyrrhenian Sea, between Cape Circeo and Sperlonga (southern Latium, Italy) an area corresponding to a coastline 30-km long between latitude 41°10′ N and 41°18′ N and longitude 013°05′ E and 013°25′ E (Fig. 1).

Material and Methods

Field work

Side Scan Sonar (SSS) was used to detect the boundaries of *Posidonia* beds and their general characteristics; direct observations by underwater towed video camera (Ardizzone 1991) were utilized to estimate the different bottom coverage (*Posidonia*, dead matte, soft or hard bottom), the position of the margins, and generally to validate the SSS interpretation. Integration of direct and indirect methods was adopted during this survey to produce the most accurate possible information on the sea bottom coverage.

When we talk of 'dead matte' we refer to the intertwined dead rhizomes of *Posidonia oceanica*, the interstices of which are filled with sediment. When *P. oceanica* leaves die the dead matte is visible at the bottom and the rhizome decays very slowly and may persist for years or centuries according to the sedimentary regime. The presence of dead matte is therefore indicative of the past presence of the meadow.

The SSS used in this study was a Towfish EdgeTech model 272 TD, equipped with a transducer transmitting an acoustic signal at a frequency varying from 100 to 500 kHz. For the present work, a 100-kHz TVG Range (100 kHz) signal with a maximum slant range of 75 m per channel on each side of the tow-fish transducer was used. The pixel resolution was 0.30 m. The transducer was dragged at an average speed of 3 knots. The ship's position was determined by a differential global positioning system (DGPS-RTK Leica 500, precision 0.50 m). The SSS data acquisition software (CODA) was real time interfaced with the DGPS data acquisition software PDS2000. Sixty navigation lines ran parallel to the coast 145 m apart, to allow sonograms to overlap. Six-hundred kilometres of sonar images were obtained along the Circeo – Sperlonga coast during a survey carried out in April 2005.

The acquisition software of SSS applies the slant-range corrections to the raw data, using navigation and depth data supplied from the ship computer log. This processing eliminates the distortions caused by the slant of the beam and fluctuations in the speed of the vessel and its sensor. The system generates real-time printing of the data received at a scale of between 1/1000 and 1/2000 and simultaneously stores the digital data on the hard disk. The resolution of restitution was 2 and 4 pixels, 100 DPI 8 bits.

The images obtained (sonograms) indicated the distribution and boundaries of the different sediment or meadow formations which are characterized by different shades of grey. The sonograms were used to discriminate *P. oceanica* beds from both rocky and sandy bottoms.

Direct observations by the towed vehicle were used to validate the indirect methods and to obtain more detailed information about the *Posidonia* beds. An underwater video camera mounted on a sledge-like frame was towed a few metres over the bottom by a supply vessel at low speed (max 2 knots). An umbilical cable 100-m long connected the camera with the control unit on board. The towed camera was equipped with a compass and a digital depth meter. The images transmitted directly to the surface allowed observations in real time. The video observations were carried out along routes orthogonal to the coast with a shooting width of around 10 m. The bathymetric interval ranged from 4 to 40 m. About 42 km of sea bottom was inspected by means of this video camera and 165 waypoints were fixed to validate the SSS sonograms. All the video images were recorded through digital media (DVCam tapes) for all the lab processing work. The boat, the DGPS and the DGPS data acquisition software were the same as those used for the SSS survey.

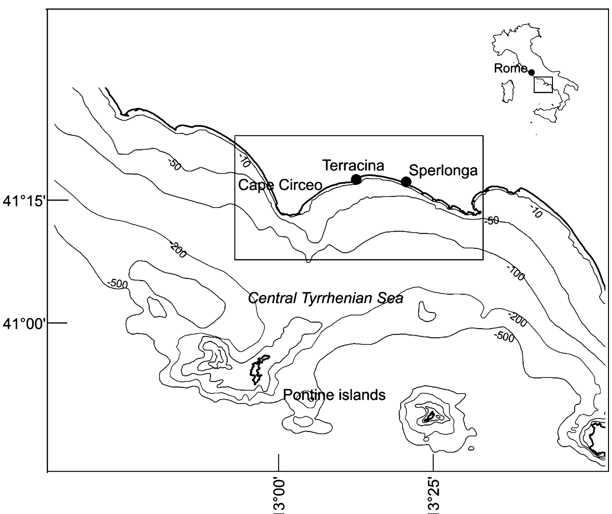

Fig. 1. The study area off the coast of Latium (Tyrrhenian Sea, Italy).

Historical map

The current distribution of *P. oceanica* in the study area was compared with the three historical maps dating back to the last 50 years: Fusco 1961 (1959 survey), Ardizzone & Migliuolo 1982 (1980 survey), Diviacco *et al.* 2001 (1990 survey). The first one is a map from the Italian

Merchant Navy made by means of discrete data from ecosounder and dredge observations. The original scale of the map is 1:100,000. The second map has been made starting from the first map, and carried out with an accurate SCUBA diving survey. The third map has been carried out within a survey on *P. oceanica* beds along the Latium coasts. The survey was carried out by SSS, Remote Operate Vehicle, SCUBA diving and DGPS positioning; the original scale of the map is 1:10,000.

ArcGIS 9.0 and ArcView 3.2 (ESRI) software were used to homogenize and to overlay the different maps. Once the total *Posidonia* coverage was obtained for the four different periods (1959, 1980, 1990 and the present 2005), the percentage decrease in the area occupied over time was estimated.

Computer simulation

The last objective of this work was to try to find a monitoring method that is the least expensive and at the same time efficient in terms of estimating the area occupied by *Posidonia*. Given a reliable starting point, this monitoring method would eliminate the need for full coverage surveys (SSS), and thus allow an easier and cheaper monitoring design. Ideally the sampling scheme should provide a reliable measure of the area of *Posidonia* with the lowest possible number of samples. Such a sampling scheme would be useful in monitoring the conservation status of *Posidonia* beds over time (by monitoring we mean a regular activity of control in an area where the distribution of *Posidonia* has already been mapped and can be utilized as reference condition). Moreover, the ability to implement a low-cost up-to-date distribution in relation to historical coverage, could allow a valid examination of the coherence of the long-term conservation trends, and offer the chance for timely action. For this purpose, a GIS simulation of the sampling effort was carried out, considering the information collected by the towed video camera on bottom strips as potentially useful sampling units of the *Posidonia* surface. The aim was to calculate from a minimum surface coverage (the Landscape Unit) operated by a towed video camera, the minimum level of information that was enough to describe with high accuracy and precision the status of the beds in the different periods. The complete information on the percentage presence of *Posidonia* was derived from the maps available.

Considering the characteristics of the data sets collected using the towed video camera, each sampling unit, hereafter called Landscape Unit (LU), was built as a north–south oriented 10-m-wide strip (the same as the shooting coverage of the video camera), and limited by the coastline (to the North) and by the depth of 35 m (to the South), according to the different functional and morphological structures of *Posidonia* beds in relation to depth (Balestri *et al.* 2003). To obtain the minimum sampling area of *Posidonia* bed that needs to be surveyed to obtain reliable estimates of the modification, resampled simulations were performed through bootstrapping resampling technique (it means that the data z_j in the original sample of size s are randomly resampled with replacement (j = 1, …s) (Kleijnen *et al.* 1998). The simulations were done on three (1959, 1990, 2005) of the four maps that represent the most diverse conditions, to evaluate significant surface values in relation to the *Posidonia* status. For the bootstrapping simulation, the study area was divided into 2895 LUs. Each simulation was composed of 2895 steps: during the first step, one LU was selected randomly and the percentage of area of LU occupied by *Posidonia* was measured. The second step added a second random LU to the first one and the percentage of area occupied by *Posidonia* was measured as the sum of the two LUs. During each of the subsequent steps, the simulation randomly added LUs and measured the percentage of area occupied by *Posidonia*. At the final step, the simulation considered all the 2895 LUs and measured the percentage of area occupied by *Posidonia* in the sum of all the LUs (*i.e.* we measured the total area of *Posidonia* in the three maps). Each step of the simulation was considered as a different sampling scheme. The first step simulated a sampling scheme with only one LU, the second step a scheme with two LUs, and the last step one with 2895 LUs covering the entire study area. For each of the three maps considered, the simulation was carried out 50 times, giving a total of 144,750 steps for each map. Using the results of the simulations, it was possible to build for each step (and for each map) the distribution of percentages. As an example, let us take the 1959 map: the simulation built the distribution of percentage areas occupied by *Posidonia* when a sampling scheme with a single LU was considered; the same was true up to 2895 LUs and for the three maps. In this way, we calculated for each step (*i.e.* for each sampling scheme) the mean per cent area occupied by *Posidonia* and the associated standard deviation. As a reference, we considered reliable all the sampling schemes that gave a standard deviation smaller than 5%, but all the distribution was calculated and any standard deviation value can be considered. The simulations were carried out in ArcGIS9 (ESRI) using an AML script.

Results

The present day coverage of *Posidonia* beds has changed radically compared with the other reference periods (Fig. 2). In fact, an estimate of 2899 ha of *Posidonia* and 1800 ha of dead matte was calculated for the 2005 survey.

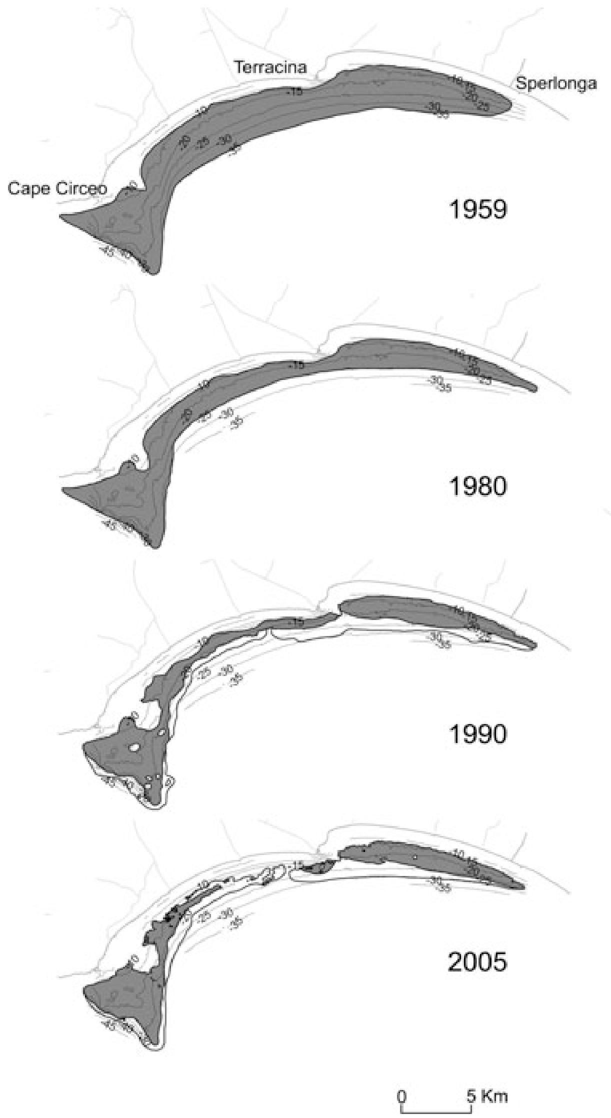

Fig. 2. The *Posidonia oceanica* meadows in the historical maps (1959: from Fusco 1961; 1980: from Ardizzone & Migliuolo 1982; 1990: from Diviacco *et al.* 2001), and in the 2005 survey (present paper).

Three sub-areas, characterized by different conditions can be identified (Fig. 2). The first sub-area (the westernmost one) is that off Cape Circeo where *Posidonia* beds were the least modified over the years. The second sub-area (the central one) is located between Cape Circeo and Terracina; here the *Posidonia* beds display the most consistent regression in time. This coast has suffered from important urban change that influenced both water quality and sediment type. The third sub-area (the easternmost one), located from Terracina to Sperlonga, showed a medium regressive status of the *Posidonia* beds, mainly characterized by the decreasing of their lower limits.

For these three sub-areas, the trend in the reduction of *Posidonia* coverage and the modification of the lower limit were estimated and different conditions were found (Fig. 3). In 1959, the lower limit of the *Posidonia* bed was *c.* 35 m in the entire study area (Fusco 1961), but it had markedly changed 20 years later (Ardizzone & Migliuolo 1982) with a mean value of *c.* 22–24 m in the most regressed central area and 25 m east of Terracina. In the 1990 survey, the lower limit showed different conditions: almost the same depth (*c.* 30–35 m) off Cape Circeo, 20–22 m in the central part of the area, and 24–25 m east of Terracina (Diviacco *et al.* 2001). In the present survey, the Circeo area is the least modified one, while in the central area the lower limit further decreased, reaching a depth of 18–20 m. In the eastern area the present limit is at 23–25 m.

The upper limit changed less than the lower one, going from 14 m in 1959 to 17–18 m in the present study, without any great diversification in the different sub-areas. The only important exception is off the harbour of Circeo. From the first estimate of *Posidonia* coverage of 7290 ha in 1959, the total area in 1980 had become 5054 ha, and 3581 ha in 1990 down to the present value of 2899 ha. At the same time, no important increase in the dead matte has been observed. We do not have any information on the dead matte area in 1959 and 1980 but a limited increase was observed in the last 10 years, comparing the estimated area of 1663 ha in the 1990 to the present value of 1800 ha, when most of the regression had already been observed.

The simulation of the different sampling schemes showed different values in relation to the status of the *Posidonia* meadows. The percentages of *Posidonia* measured considering the entire surface of the study area were 69.39% in 1959, 34.31% in 1990 and 27.72% in 2005. For the 1959 map that represents the best and the most regular condition, the simulation suggested that a sampling scheme with only nine randomly selected LUs provided the minimum possible effort for obtaining a reliable estimate of the area of *Posidonia*. In fact, nine randomly selected LUs gave a mean estimate of 70.05% of *Posidonia* with a standard deviation of 4.92%. In 1990, the minimum sampling effort required to estimate the condition of *Posidonia* was of 18 randomly selected LUs, corresponding to a mean percentage of 34.91% with a standard deviation of 4.98%. In 2005, 21 randomly selected LUs gave a mean of 27.42% with a standard deviation of 4.89% (Fig. 4). To reduce the standard deviation to a value of roughly 1%, we need 221 LUs for 1959 (mean 69.16, SD 0.99%), 340 LUs for the 1990 distribution (mean 34.25, SD 0.99%) and 480 LUs for the 2005 distribution (mean 27.73, SD 0.99%).

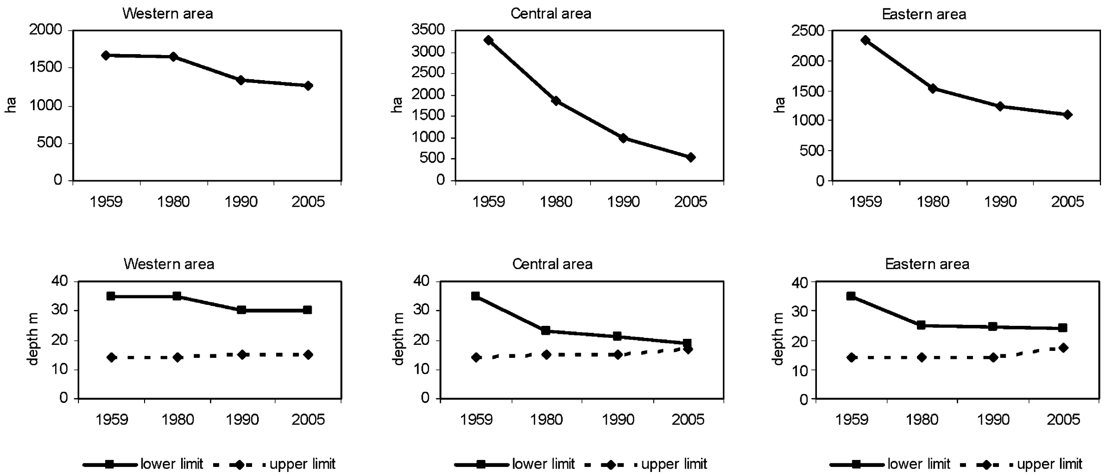

Fig. 3. Trend of the *Posidonia oceanica* bed coverage (above) and of lower and upper limits of the *Posidonia* beds (below) in the 1959, 1980, 1990 and 2005 maps and in the different sub-areas.

Discussion

The very heterogeneous status of the *Posidonia* beds observed in the 30-km long study area stresses the need for large-scale studies to understand the complex level of modification, which is particularly important in cases of regression. The relatively rapid regression observed here can be summarized in the reduction of the bottom coverage by *c.* 60% since 1959, 19% of which has occurred since the last survey dating back to 1990. The total loss of *Posidonia* beds amounted to 4391 ha in the last 50 years. The extent of this loss is however different in the three main sub-areas. The zone off Cape Circeo showed a little reduction of the overall surface and lower limits, probably because the seagrass meadows are located offshore and therefore are less influenced by continental inputs. However, this area is also characterized by the presence of hard bottoms, that prevent damage as a consequence of illegal coastal trawling. The exception is the zone immediately off the harbour of Circeo. This important coastal harbour, realized in the 1960s, markedly modified the *Posidonia* bed creating a big discontinuity in its distribution that can be clearly seen from the first image to the present condition (Fig. 2).

The middle area showed the most dramatic coverage and meadow limits reduction. As stated before, this area was subjected in the past years to different human impacts that lead to a heavy coastal erosion and turbidity of seawaters. Furthermore, an illegal trawling activity is today carried out. Finally the third sub-area, from Terracina to Sperlonga, displayed a medium condition of meadow extension and limits regression (Figs 2 and 4). This area is less subject to erosional phenomena, turbid water, illegal trawling and, more general, to human impacts.

The validation of old maps is a main test for their usefulness (Leriche *et al.* 2004). The 1990 and the present maps can be considered fully reliable, in our case the latter being implemented by SSS full coverage sonograms, validated by video camera and located by DGPS. The other old maps deriving from the interpolation of discrete data, are important for the upper and lower limits of tidily distributed *Posidonia*.

Contrary to the rapid regressive condition of the meadow, the coverage of dead matte does not appear to be proportionally increasing. The reason for this lies in the structure of the matte. The low-lying matte of the study area suffers from physical impact (trawl fishing) and heavy siltation. The dead matte, somewhat eroded and somewhat covered up by sediment, tends to disappear and therefore is detectable neither by SSS nor by video camera. The 1990 maps and present maps can explain this condition. These two maps have similar total dead matte surfaces (1663 and 1800 ha) but with different geographic position due to the shifting of the dead matte strip towards the lower *Posidonia* limit. This limit is moving towards the coastline, the new dead matte is following the limit, and the old dead matte is disappearing, being eroded and covered by sediment.

This current critical condition is not the result of catastrophic pollution but is certainly due to the anthropogenic modifications very common in almost every Mediterranean coastal zone (Boudouresque *et al.* 2006). Rapid growth of the human settlements, building of new harbours and breakwaters, input of nutrient coming from the intensive agriculture of the area, and the illegal trawl fishing still being carried on (Ardizzone *et al.* 2000), are without any doubt the joint causes of the observed regressions.

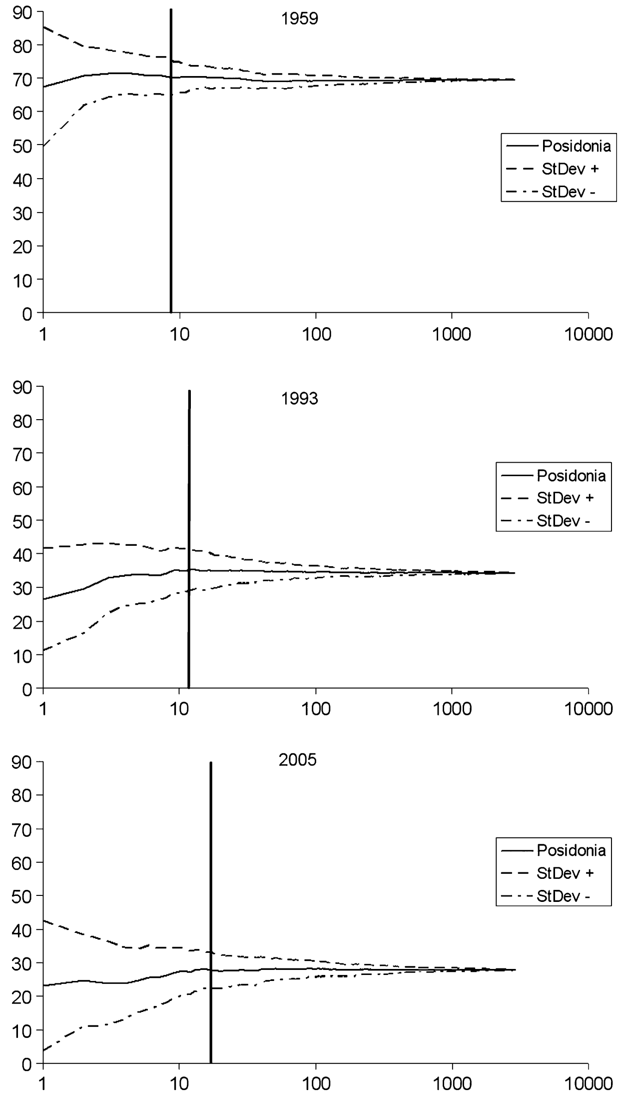

Fig. 4. Average percentage of *Posidonia oceanica* coverage ±SD obtained from GIS simulation for the 1959, 1990 and 2005 maps.

Evidence of the connection between coastal modification and regression of *Posidonia* can be found also when comparing the described *Posidonia* to the status of the *Posidonia* meadows in the Pontine Islands, just off the study area. None of the above mentioned impact factors is present in those islands and the *Posidonia* coverage of the sea bottom is stable, and certainly has been so in the last 15 years (G.D. Ardizzone 1991, unpublished observations 2005), and without any sign of modification such as the presence of dead matte.

A good knowledge of the *Posidonia* distribution but at the same time little well-documented information on historical modification of the meadows is the present general condition of the Italian coastal areas and that of other Mediterranean countries, as well. The general status of regression reported in many scientific works is mainly linked to spot information on the amount of dead matte observed in a present day distribution, thus preventing any evaluation of the dynamic trend of the meadow coverage. But this problem is not only a Mediterranean one. As reported by Short & Wyllie-Echeverria (1996) 'a realistic estimate of present seagrasses loss worldwide is not possible and the few available quantitative reports are certainly an underestimate of overall loss'. Australia, the most important continent as to the number of species of seagrasses and sea bottom coverage, is reported to be endangered for some species, which have regressed by 45,000 ha in 11 sites (Walker & McCombe 1992), but is this an important area in relation to the overall amount of Australian seagrasses or is it negligible? We cannot answer this question. A similar question is that of the 90,000 ha loss reported for the worldwide decline (Short & Wyllie-Echeverria 1996).

The results obtained with the simulations for the three different maps of the *Posidonia* beds over time showed that significant information can be obtained on the status of a meadow already mapped, with a limited sampling effort and with high accuracy and precision (SD < 5%) being yielded in the description of the *Posidonia* surface. The sampling effort necessary to reach 1% of the standard deviation value is very high (respectively 221, 340, 480 LUs) and therefore the objective of low cost monitoring is lost. With only 9, 18, and 21 LUs, we obtained a good description of the bottom coverage in 1959, 1990, and 2005, respectively, with a 5% standard deviation value. Moreover, it is evident that the number of the minimum LUs samples increased in time, as the more regular is the *Posidonia* distribution, as in the case of the oldest map, the more limited is the sampling effort needed. The surface percentage covered by the towed video camera, which is useful to describe the whole *Posidonia* distribution, amounted therefore to 0.3% of the total area for the 1959 map, 0.6% for that of 1990 and 0.7% for the 2005 one.

Modern techniques to produce *Posidonia* bed cartography at a vast macro-scale are nowadays very advanced and include different kinds of surveys (SSS, video camera or ROV, diving), data analysis and GIS elaboration. Their cost is anyhow still very expensive. While an initial important effort to obtain detailed reference cartography for each *Posidonia* meadow is understandable, the same effort is not feasible and realistic in a regular monitoring programme. The evidence of reduction in survey costs with these limited sampling surfaces could allow the planning of regular monitoring programmes implemented by towed video camera systems. The costs of these instruments is relatively low, their use is very simple, needing small craft and a positioning system by means of GPS or DGPS implemented by a plotter system. Sampling units orthogonal to the coast, which are useful to estimate significant portions of seagrass beds, should always be adopted and the need for a stratified sampling design should be considered in the allocation of the random LUs when different characteristics of the distribution are present.

This kind of survey is currently being used to validate aerial photographs or SSS sonograms for the correct identification of unidentified patches. The experience already obtained evidenced the potentiality of towed underwater video surveys to monitor very large and already mapped *Posidonia* beds with limited and low-cost surveys.

Summary

During a monitoring work along the Latium coast (Central Tyrrhenian Sea) a detailed cartography of *Posidonia oceanica* beds was implemented by means of SSS and towed video camera techniques in 2005. This cartography has been compared with several historical maps dating back over the last 50 years (1959, 1980 and 1990). Moreover, using bootstrap simulations, we were able to obtain the percentage of sea bottom that should be assessed to understand the change in relation to a reference condition. In 1959, the lower limit of the *Posidonia* bed was around 35 m in the entire study area. Only 20 years later the value was around 22–24 m, while in the 1990 survey the lower limit was at 20–22 m, and in 2005 it was reduced to 18–20 m depth. The total area of *Posidonia* changed from 7290 ha in 1959 to 5054 ha in 1980, and from the 3581 ha in 1990 down to the current value of 2899 ha, to a total loss of about 60%. The current critical condition is due to anthropogenic modifications very common in almost every Mediterranean coastal zone. Computer simulations were made on the three maps (1959, 1990, 2005) that represent the most diverse conditions. Sampling units (Landscape Units, LUs) were set up as a north–south oriented strip 10 m wide, and limited by the coastline and by the 35 m depth. The results obtained with the simulations showed that significant information could be obtained on the status of a meadow already mapped, with a limited sampling effort and yielding a 95% significant description of the *Posidonia* surface. With only 9, 18 and 21 LUs, respectively, we obtained a good description of the bottom coverage in the three periods 1959, 1990 and 2005. The evidence of reduction of survey costs with these limited sampling surfaces could allow the planning of regular monitoring programmes implemented by towed video camera systems.

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