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# Continuous mapping of benthic habitats along the coast of Corsica: A tool for the inventory and monitoring of blue carbon ecosystems

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## Abstract

Continuous mapping of the benthic marine habitats along the coast of Corsica is based on a synthesis of all available historical data as well as new studies concerning sectors that are poorly taken into account and/or that are of particular interest. The mapped area covers more than 310 000 ha, almost all infralittoral and circalittoral, with a survey up to 150 m deep around the coast of Cap Corse. While within the infralittoral zone, *Posidonia oceanica* meadows are predominant, with a surface area of about 53 735 ha, in the circalittoral zone, soft bottoms (eg coastal detritic bottoms) are largely dominant, with the rhodolith association particularly well represented (26 493 ha). The coralligenous biocenosis (2 111 ha) covers relatively small areas but includes unique formations at Mediterranean scale: the coralligenous atolls. The reliability scale proposed to assess the accuracy of these maps shows satisfactory results (62% on average), with a higher value for the infralittoral zone (74%). The results confirm that Corsica's coastline is characterized by a significant expansion of the Blue Carbon ecosystems, and in particular the *Posidonia oceanica* meadows, which regularly reach more than 35 m depth and cover 61% of the of the seabed between 0 and -40m, and free-living coralline algae (8% of the known surfaces in the western Mediterranean basin). The areas covered by *Posidonia oceanica* in the Mediterranean basin are estimated at between 1.0 and 1.5 million hectares, and show a decreasing pattern along a north-west to southeast gradient.

**Keywords:** Corsica; benthic mapping; reliability; Blue Carbon ecosystems; *Posidonia oceanica*.

## Introduction

Monitoring of the surface area covered by key habitats is a regularly used indicator to assess progress in environmental management (Levrel *et al*., 2010), due to its importance for the implementation of European policies for the protection and conservation of the marine environment, such as the Habitats Directive (HD, 92/43/EEC), the Water Framework Directive (WFD, 2000/60/EC), the Common Fisheries Policy (CFP, COM(2010)241) or the Recommendation on the Integrated Coastal Zone Management (2002/413/EC), and more recently the Marine Strategy Framework Directive (MSFD, 2008/56/EC). While this tool often proves to be effective in terrestrial environment, thanks to the level of knowledge available, in marine environment this strategy often runs up against the absence of earlier data which might enable the reconstitution of the spatio-temporal patterns of change, even though mapping of benthic habitats and bottom types has increased since the beginning of the 21st century (Telesca *et al*., 2015). However, even if several works have resulted in an improvement in the level of knowledge, as regards the distribution of *Posidonia oceanica* (L.) Delile meadows (Telesca *et al*., 2015; Poursanidis *et al*., 2018; Topouzelis *et al*., 2018) and other habitats (Ballesteros, 2006; Agnesi *et al*., 2009; Martin *et al*., 2014), data are still rather too sparse to provide an adequate basis for responding to international commitments and conservation issues (Gubbay *et al*., 2016).

Similarly, in the context of climate change, the Paris Agreement stresses that "*Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases*", and states that a national inventory report of these greenhouse gas sinks will have to be provided (FCCC, 2015). In the Mediterranean coastal environment, these sinks are mainly represented by blue carbon ecosystems, and in particular the seagrass meadows that provide a large part of the fixation, and especially the sequestration, of organic carbon (Mateo & Romero, 1997; Nellemann *et al*., 2009; Fourqurean *et al*., 2012; Pergent *et al*., 2014; Herr & Landis, 2016). Nevertheless, free living coralline algae (eg maërl), and coralligenous habitats that potentially cover extensive areas in the Mediterranean Sea, have a significant capacity to store inorganic carbon over long periods of time (Martin *et al*., 2014; Van der Heijden & Kamenos, 2015), even though they may be considered as a source of $CO_2$ for surrounding environments (Martin *et al*., 2007).

At Mediterranean regional scale, Corsica is a textbook case insofar as it has since the late 90s been the focus of a first mapping survey of the main habitats and bottom types down to 40 m depth from its littoral zone (Pasqualini *et al*., 1998), and since the late 2000s, a general map of the geomorphology of the bottom down to 100 m depth (Pluquet, 2006). In addition, since 2010, several scientific programs (CapCoral 2010-2011, CartHaM 2010-2013, CoralCorse 2013 and MedAtolls 2014) have provided a framework for acquiring additional data on the benthic key-habitats distribution, particularly in offshore locations, declared by France under the Natura 2000 network.

The aim of this work is to combine all available data to produce a continuous and homogeneous map of all coastal habitats of Corsica, and to assess its reliability, in order to understand the temporal patterns of change of these benthic habitats to assess the fixation and sequestration of blue carbon in the Mediterranean.

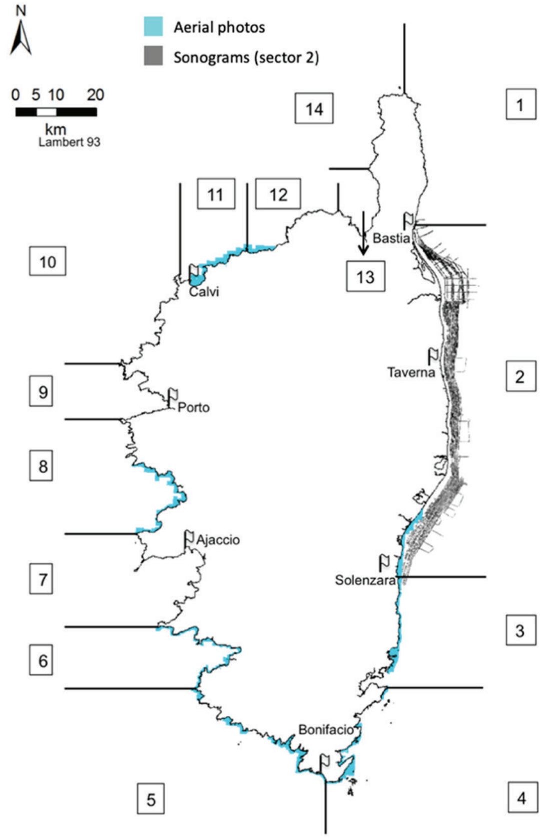


***Fig. 1:*** Location of the different sectors of the Corsican coastline (according to Meinesz *et al*., 1990), aerial photographs (in blue) and sonograms (in gray) of the NATURA 2000 site *Grand herbier de la Côte Orientale*

## Material and Methods

The approach adopted consists in:

i. Selecting the most relevant map data based on the survey date, acquisition method and accuracy, from the 293 documents, collected and compiled since 1960 (Valette-Sansevin *et al*., 2015). To facilitate the consultation of the different selected maps, the coastline was divided into 14 homogeneous sectors (Fig. 1), as defined by Meinesz *et al*. (1990), and integrated into a Geographic Information System (GIS; ArcGIS 10.2.2 software, Esri™; projection Mercator-WGS84).

ii. Updating data in areas for which "historical" information is too sparse, using aerial images, for shallow sites (0 to 10 m), and information from side scan sonar for waters deeper than 10 m (Fig. 1). Thus, remote sensing was applied to aerial photographs (BDOrtho®IGN, pixel of 0.5 m), according to the method of Bonacorsi *et al*. (2013), and an oceanographic survey (PosidCorse) was carried out aboard the IFREMER oceanographic vessel L'Europe, from 4th to 28th August 2015, at the Natura 2000 site *Grand Herbier de la* Côte *Orientale* (between 10 and 50 m deep). Seatruths were mainly performed using a bathyscope for the shallow waters (up to -10m) and a super GNOM ™ Remotely Operated Vehicle (ROV) and a GoPro-Hero3 camera attached to the side scan sonar for the deeper waters (Pergent *et al*., 2017).

iii. Homogenizing all available data according to the typology of the benthic biocenosis of the Mediterranean Sea by Michez *et al*. (2011) and collating them in a Geographic Information System (GIS). To achieve this synthesis, all the data are projected in Lambert 93 coordinate system using ArcGis 10.2.2 software.

iv. Assessing the confidence that can be placed in the various maps produced, by means of a reliability metrics established on the basis of existing scales (Pasqualini *et al*., 1998; Leriche *et al*., 2004; MESH, 2008). The assessment was carried out on the basis of 12 criteria (Table 1), relating to the different phases of map production (e.g. data acquisition, *in situ* validation and interpretation). A score between zero and three was allocated to each criterion (Valette-Sansevin, 2018). The final assessment was expressed as a percentage reliability given by the sum of the partial scores for each zone in each map, subsequently converted into classes (Table 2).

## Results

The mapped area along the coast of Corsica covers more than 310 000 ha. It includes almost all mediolittoral, infralittoral and a large part of the circalittoral populations, with a survey extending down to 150 m depth at Cap Corse (Fig. 2).

Mediolittoral habitats occupy extremely small areas (0.02% of the mapped surface), however, they can shelter 'natural monuments' such as *Lithophyllum byssoides*

**Table 1.** Reliability Assessment Scale.

| Criteria of assessment | 3 POINTS | 2 POINTS | 1 POINT | 0 POINT |
|---|---|---|---|---|
| Coverage of raw data | 100% | 75 to 99% | 50 to 74% | < 50% |
| Positioning - Georeferencing | Differential GPS | GPS or other non-satellite navigation system | Marine chart or remarkable alignment | Estimate or no geographic survey |
| Type of habitats | Very different | Different | Close | Very close |
| Slope - topography | Low and constant | Low and irregular | Steep and constant | Steep and irregular |
| Exploitation of the raw data | 100% | 75 à 99% | 50 à 74% | < 50% |
| Pixel size or map scale or<br>Water level relative to sonar range | Pixel < 0.5 m<br>Scale < 1/2 000<br>W < 10% range | 0.5 m to 2.0 m<br>1/2 000 to 1/10 000<br>10% to 19% | 2.1 m to 5.0 m<br>1/10 001 to 1/25 000<br>20% to 50% | > 5.0 m<br>> 1/25 000<br>> 50% |
| Field data (groundtruth) area | >=10% | 5 to 9% | 1 to 4% | < 1% |
| Density of field data (groundtruth) | Number of data > 20 km$^{-2}$ | 11 to 20 data.km$^{-2}$ | 1 to 10 data.km$^{-2}$ | < 1 data.km$^{-2}$ |
| Level of detail | Classes defined on the basis of a detailed biological analysis | Classes defined on the basis of the main species | Classes defined on the basis of physical data or general biological zones | Classes defined without field data or defined on the basis of historical data |
| Identification of habitats | Clear identification and clear limit position | Clear identification but unclear limit position | Unclear identification | No information available |
| Method used for interpretation | GIS software and remote sensing software | GIS software and image editing software | Image editing software | Manual drawing |
| Percentage of accuracy<br>With external data<br>Without external data | >= 80% | 60 to 79%<br>>= 80% | 50 to 59%<br>60 to 79% | < 50%<br>≤ 60% |

**Table 2.** Distribution class reliability (expressed as a percentage).

| Limits | x > 80% | 80 ≤ x < 70 | 70 ≤ x < 60 | 60 ≤ x < 50 | x ≤ 50% |
|---|---|---|---|---|---|
| Qualification | High | Good | Normal | Poor | Bad |

(Lamarck) Foslie rims, especially at sector 9.

In the infralittoral zone (0 to -40 m), *Posidonia oceanica* meadows cover an area of approximately 53 735 ha (about 61% of the seabed), while the other seagrass *Cymodocea nodosa* (Ucria) Ascherson covers only 1 690 ha (2%). In addition to the considerable surface area covered, *Posidonia oceanica* meadows erect several very rare morphotypes, considered as 'natural monuments', the reef formations (barrier reefs, reef platform, tiger meadows and atolls). The soft bottom, with an area of 25 261 ha, represents nearly 29% of the infralittoral zone, with a predominance of well-calibrated fine sand.

In the circalittoral zone, soft bottoms (e.g. detritic coastal) are largely dominant (85%). The rhodolith association occurring on these seabeds is particularly well represented, with 26 493 ha (12%). Even if hard bottoms and coralligenous biocenosis covered only 5 453 ha and 2 111 ha respectively, they exhibited locally unique formations: the 'coralligenous atolls'. Several hundred atolls, with an average diameter of 25 m (Fig. 3), were identified north of Cap Corse (sector 1). These structures, of which the origin and dynamics have not yet been fully elucidated, also appear as veritable 'natural monuments' with respect to their rarity, their age (> 7 600 BP years) and their bathymetric position (between -110 m and -130 m).

At the NATURA 2000 site *Grand herbier de la côte orientale* (sector 2, Fig. 2) seagrass meadows have the most extensive surface area, with 20 425 ha for *Posidonia oceanica* and 798 ha for *Cymodocea nodosa*, respectively more than 38% and 47% of the seagrass beds of the Corsican littoral. For the rhodolith beds, the maximum extension is observed at Cap Corse and Agriates (sectors 1, 12, 13 and 14), with more 21 044 ha (nearly 80%) of bottoms where this association is to be found.

The reliability scale shows 'normal' values (61%) for the entire coastline of Corsica, but this value is higher for the infralittoral (74% - 'good') than for the circalittoral zone (56% - 'poor'; Table 3). In general, the average reliability is slightly higher on the eastern (62%) than on the western (59%) coastline (Table 3).

## Discussion

Since the 1990s, the cartographic tool has been increasingly used in marine spatial planning and management (Harris & Baker, 2012), as evidenced by the growing trend in the number of scientific papers published

**Table 3.** Mean reliability (in%) of the different sectors of the Corsica coastline.

| Sectors | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Infralittoral** | 83 | 75 | 75 | 76 | 68 | 62 | 69 | 67 | 69 | 69 | 77 | 79 | 81 | 78 |
| **Circalittoral** | 77 | 51 | 37 | 52 | 43 | 33 | 65 | 48 | 69 | 63 | 27 | 69 | 74 | 74 |
| **Average** | 78 | 62 | 50 | 57 | 48 | 47 | 67 | 57 | 69 | 64 | 40 | 71 | 76 | 74 |

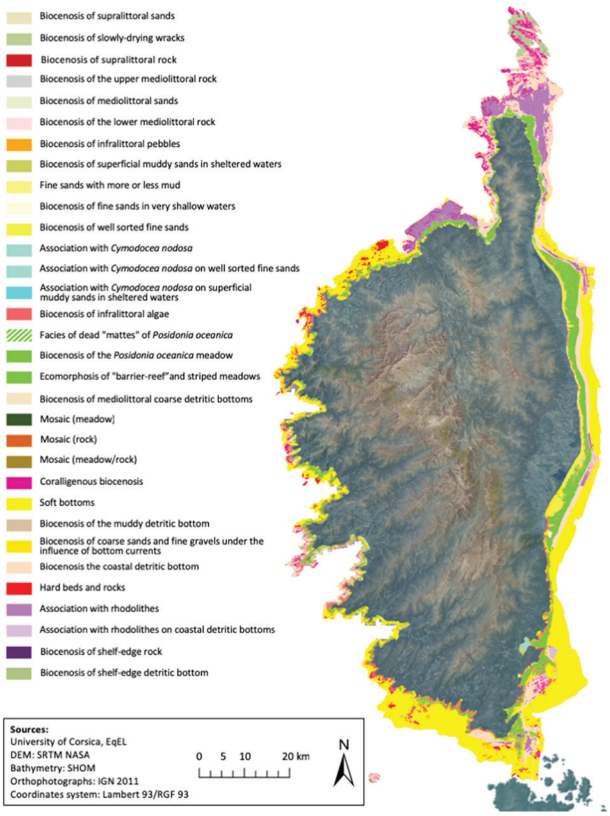


***Fig. 2:*** Continuous mapping of benthic habitats and bottom types along the coast of Corsica.

(Diesing *et al.*, 2016). The coastline of Corsica (1 200 km in http://gadm.org/country) perfectly illustrates this trend, with the availability of maps that cover the entire coastline of the island, and sometimes with several for the same area (Valette-Sansevin *et al.*, 2015).

The advances in the means of investigation available to scientists (high resolution airborne images, remote sensing software, side scan sonar, multibeam echosounder, LIDAR, ROV, etc.), enable the optimization of mapping methods (survey accuracy, habitat detection and identification) and their application to extensive areas. Thus, the installation of a GoPro™ camera, under side scan sonar, enables the calibration of the acoustic data, and the real-time identification of the habitats present on the sonograms (Pergent *et al.*, 2017). Similarly, improvements in sensors (optical and acoustic) now make it possible to detect *Cymodocea nodosa* meadows both in shallow waters and beyond the lower limit of *Posidonia oceanica* meadows, at depths of more than 35 m (Fig. 4).

The extensive areas of seagrass in the infralittoral can be explained by several factors:

i. High water transparency, due in part to the reduced number of permanent coastal rivers, low population pressure (38 inhabitants per km$^2$, www.populationdata.net), little industry and a rate of coastal development among the lowest in the western Mediterranean (less than 0.5% of shallow waters between 0 and 20 m depth, www.medam.org).
ii. Particularly favorable topography, especially along the eastern coast, where the very gradual slope allows *Posidonia oceanica* meadows to extend up to more than 5 km from the shore (Pasqualini *et al.*, 1998).

With a value of 45.7 ha per kilometer of coastline, the seagrass occupancy rate of *Posidonia oceanica* along Corsica's coastline is higher than that observed along the French continental coastline. A similar situation is recorded at the scale of the whole Mediterranean Basin with, in general, higher occupancy rates around the large Mediterranean islands than in the corresponding continental littoral areas (Spain, France, Italy, Greece; Table 4).

On the other hand, there is a decreasing gradient of coverage of *Posidonia oceanica* seagrass beds along a

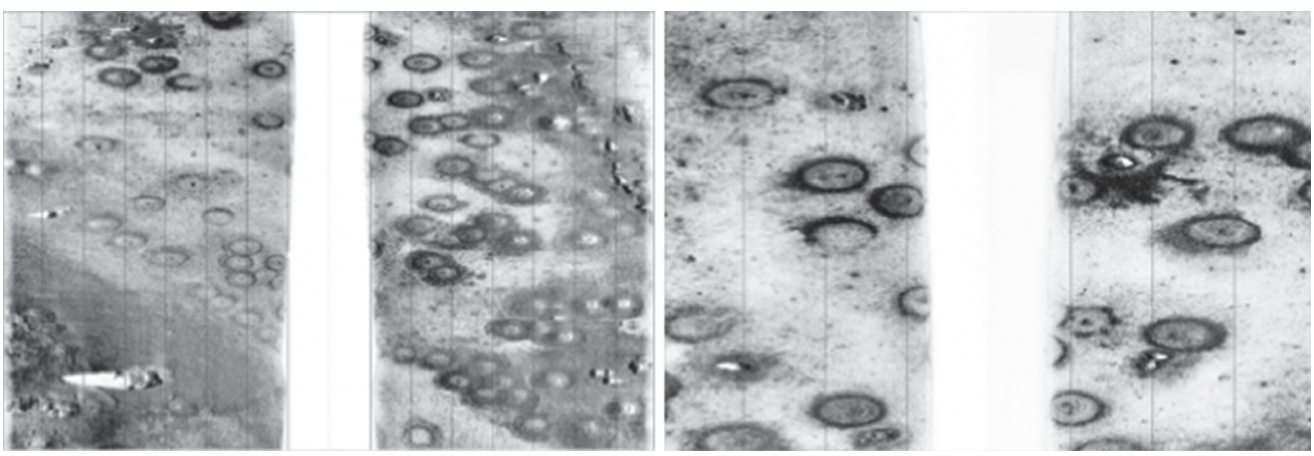

***Fig. 3:*** Coralligenous atolls on a sonogram, general view (left) and details (right).

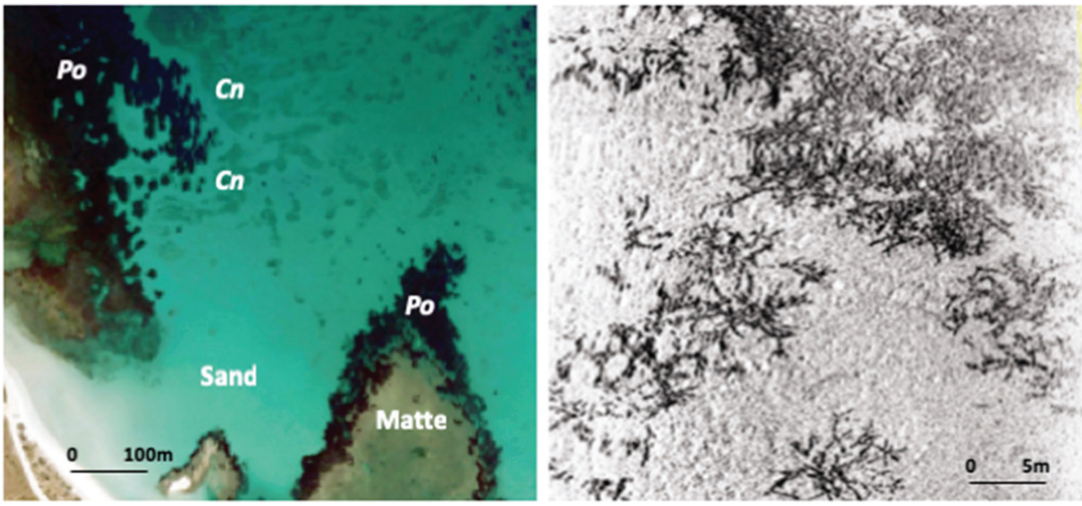


***Fig. 4:*** Shallow (aerial photo) and deep (sonogramm, -35 m) *Cymodocea nodosa*. *Po* = *Posidonia oceanica*, *Cn* = *Cymodocea nodosa*.

**Table 4.** Areas covered by the *Posidonia oceanica* meadow in different countries and large islands of the Mediterranean basin (from Ruiz *et al*., 2015[1]; Quemmerais-Amice, 2018[2]; Valette, 2018[2,3]; Ministero dell'Ambiente e della Tutela del Territorio, 2001[4], Traganos *et al*., 2018[5]; Calvo *et al*., 2010[6]; Topouzelis *et al*., 2018[7]; Telesca *et al*., 2015[8]; Pergent-Martini *et al*., 2013[9]). * http://gadm.org/country ; ** http://portal.emodnet-bathymetry.eu/.

| | Length of coast-line in km (GADM*) | Bottom surface area between 0 and -40 m, in ha (Emodnet**) | Surface area covered by *P. oceanica* in ha | Surface area cov-ered by *P. ocean-ica* in ha, par km of coastline | Bottom % cov-ered by *P. oceanica* between 0 and -40 m |
|---|---|---|---|---|---|
| Spain (Medit.)[1] | 4 024 | 606 262 | 115 904 | 28.8 | 19.1% |
| France (Medit.)[2] | 2 476 | 268 467 | 87 680 | 35.4 | 32.7% |
| Italy[4] | 11 403 | 3 068 310 | 337 611 | 29.6 | 11,0% |
| Greece[5] | 14 880 | 4 095 100 | 251 010 | 16.9 | 6.1% |
| Balearics[1] | 1 435 | 112 022 | 63 316 | 44.1 | 56,5% |
| Corsica[3] | 1 177 | 88 509 | 53 735 | 45,7 | 60,7% |
| Sardinia[4] | 2 403 | 303 740 | 153 382 | 63,8 | 50,5% |
| Sicily[6] | 2 007 | 318 393 | 76 000 | 37,9 | 23,9% |
| Crete[7] | 1 590 | 64 910 | 14 500 | 9.1 | 22,3% |
| Cyprus[8] | 648 | 93 174 | 9 040 | 14.0 | 9,7% |
| Cyprus Natura 2000[9] | 148 | 23 806 | 3 627 | 24,5 | 15,2% |

north-west / south-east axis. Several abiotic factors could be the cause of this gradient, in particular the higher summer temperatures in the south-east of the eastern basin, where the values are close to the tolerance thresholds of the species (Celebi *et al*., 2006; Marbà & Duarte, 2010), and also a decline in the available resources (water oligotrophy).

At Mediterranean scale, the area covered by *Posidonia oceanica* meadow has been estimated between 2.5 and 4.5 million hectares (Pasqualini *et al*., 1998), but more recently the synthesis of Telesca *et al*. (2015) and the new data for Greece and Turkey seem to suggest a lower value between 1.0 and 1.5 million hectares (Topouzelis *et al.*, 2018, Traganos *et al*., 2018; Akçalı *et al*., 2019. In fact, the areas covered by *Posidonia oceanica* in Greece (32% of the Mediterranean coasts) are relatively limited compared to those recorded in the north-western basin, with an average of 17 ha.km$^{-1}$ of coast against 30 ha.km$^{-1}$ on average on (? along) the coasts of Spain, France and Italy (Table 4).

In the circalittoral zone, the high transparency of the waters enables the exceptional bathymetric extension of the rhodolithic beds and coralligenous assemblages for the western Mediterranean. These bioconstructed habitats are observed down to -130 m off Cap Corse (Bonacorsi *et al*., 2012), whereas they seldom exceed -90 m in the literature (Barbera *et al*., 2003; Ballesteros, 2006; Aguilar *et al*., 2009; Martin *et al*., 2014). In addition, the surface areas of rhodoliths, mapped at Cap Corse (sectors 1, 12, 13 and 14), represent nearly 8% of the known surface areas of this association in the western Mediterranean (Martin *et al*., 2014).

Nevertheless, at Mediterranean level, historical data are still limited even for key stands such as seagrass meadows, although 85% of the coast has been surveyed recently (Telesca *et al*. 2015; Topouzelis *et al*., 2018). In addition, when these data exist, due to advances in underwater mapping techniques and the lack of previous sea-truthing, the comparison of results remains difficult (Leriche *et al*., 2004; Borg *et al*., 2009; Montefalcone *et al*., 2014). The coast of Corsica, where there have been numerous cartographical studies since the 1990s, is therefore an exception, and constitutes a unique workshop site able to inform us on the temporal patterns of change of a key habitat, the *Posidonia oceanica* meadow. Since the first map of the *Posidonia oceanica* meadows of the entire coast of Corsica, carried out by aerial images and side-scan sonar between 1994 and 1997 (Pasqualini *et al*., 1998), several studies have made it possible to specify (? have provided a basis for the precise determination of) the distribution of this habitat. These include, in the early 2010s, Cartham, CapCoral, CoralCorse and more recently the PosidCorse oceanographic survey in 2015 (Valette-Sansevin *et al*., 2015, Table 5).

The decline in the surface area observed for this habitat (nearly 14% on average since 1994) cannot be solely attributed to the regression of the *Posidonia oceanica* meadows, while anthropic pressures have remained limited. This is confirmed by the results of the Posidonia Monitoring Network, set up in 2004, which shows the overall stability of the seagrass beds at depth and the absence of recent dead matte beyond them (Pergent *et al*., 2015). The differences noted seem rather related to advances in the mapping techniques (greater accuracy) and the consequent reduction of the role of interpolation. This hypothesis is confirmed at the NATURA 2000 site *Grand Herbier de la*Côte *Orientale* where, because of the significant degree of interpolation performed between the upper and lower limits, the seagrass surface areas were estimated at 22 957 ha by Pasqualini *et al*. (1998), whereas in reality they cover only 20 425 ha (presence of many natural erosive structures and anthropogenic traces not taken into account initially). Similarly, at several Cap Corse sites, where the degree of interpolation is considerably less, the 'regression of meadows' would only appear to be between 1 and 2% (Bonacorsi *et al*., 2013).

The availability of these data (surface area covered by *Posidonia oceanica*), at the scale of Corsica, enables a first estimate of the amounts of carbon fixed by this meadow. Based on the average amount of organic carbon fixed in the NATURA 2000 site *Grand Herbier de la* Côte *Orientale*, 1.61 tons C $ha^{-1}.year^{-1}$ (in Valette, 2018), it is possible to extrapolate this fixation to an estimation of around 87 000 tons $C.year^{-1}$ for the entire coast of Corsica, and between 1.6 and 2.4 million tons $C.year^{-1}$ for the Mediterranean as a whole. Annual *Posidonia oceanica* carbon fixation would correspond to a value between 0.3 and 0.4% of the carbon dioxide emissions emitted by all 21 of the Mediterranean countries in 2017 (http://www.globalcarbonatlas.org /en/CO2-emissions). In addition to annual carbon fixation, its sequestration within the matte, a barely putrescible structure likely to persist for thousands of years, constitutes a unique carbon sink (Mateo & Romero, 1997; Monnier *et al*. 2019).

## Conclusion

Monitoring of the surface area covered by key benthic habitats, and especially the seagrass meadow, is often

**Table 5.** Changes in the surface areas covered by *Posidonia oceanica* meadows along the coastline of Corsica (in ha). In gray, sector 2 covered by the PosidCorse survey. [1]Meinesz, 1990; [2]Pasqualini *et al*. (1998), [3]Valette-Sansevin *et al*. (2015). *: Potential surface areas estimated but not mapped.

| Study period | 1990[1*] | 1994-1997[2] | 2010-2015[3] | This work | % variation 1994 / 2018 |
|---|---|---|---|---|---|
| Sector 1 | 4 788 | 4 660 | 4 137 | 4 137 | -11,2% |
| Sector 2 | 26 151 | 22 957 | 22 188 | 20 425 | -11,0% |
| Sector 3 | 3 974 | 3 129 | 3 114 | 3 078 | -1,2% |
| Sector 4 | 7222 | 6 917 | 6 192 | 6 179 | -10,5% |
| Sector 5 | 6 027 | 3 890 | 3 582 | 3 534 | -7,9% |
| Sector 6 | 2 801 | 1 860 | 1 509 | 1 430 | -18,9% |
| Sector 7 | 4 886 | 3 758 | 2 765 | 2 765 | -26,4% |
| Sector 8 | 4 387 | 3 520 | 3 071 | 2 981 | -12,8% |
| Sector 9 | 1 285 | 1 100 | 763 | 763 | -30,6% |
| Sector 10 | 1 994 | 1 405 | 719 | 719 | -48,8% |
| Sector 11 | 2 471 | 1 923 | 1 532 | 1 505 | -20,3% |
| Sector 12 | 4 044 | 3 522 | 2 944 | 2 940 | -16,4% |
| Sector 13 | 2 427 | 2 014 | 1 784 | 1 784 | -11,4% |
| Sector 14 | 3 140 | 1 710 | 1 497 | 1 497 | -12,5% |
| Total | 75 593 | 62 363 | 55 797 | 53 735 | -13,8% |

used as an indicator to assess the state of the environment (eg Habitat Directive, Marine Strategy Framework Directive).

Unfortunately, long time series are too sparse, except at limited sites (e.g. Marine Protected Areas), to accurately reconstruct the spatio-temporal patterns of change in these habitats (Gatti *et al*., 2017). On the other hand, when these data exist, the precision of the underwater mapping methods used is very variable (Leriche *et al*., 2004; Borg *et al*., 2009; Montefalcone *et al*., 2014). It is thus difficult to distinguish between the real changes in the surface area covered by these habitats and the apparent changes linked to the improvement in map accuracy (Bonacorsi *et al.*, 2013; Pergent-Martini *et al*., 2017). Furthermore, if the use of the surface area indicator is to be acceptable, it must integrate the reliability of the maps, and the bias that may affect the quality of the result (eg sensor accuracy, interpolation percentage, number of sea-truth verifications, type of projection used).

For effective monitoring of the patterns of change in benthic habitats, two approaches should be favored:

Use raw previous data (aerial photography, sonograms) that can be reinterpreted using the same methods as those used for recent data (Bonacorsi *et al*., 2013; Holon *et al*., 2015).

Monitor reference sites, representative of these habitats along a coastline, by setting up an accurate and reproducible monitoring system, (Boudouresque *et al*., 2000; Pergent *et al*., 2007, 2015; Montefalcone *et al*., 2018).

These approaches are also essential for assessing the sensitivity of these habitats to climate change (Bianchi & Mori, 2004; Pergent *et al*., 2015; Montefalcone *et al*., 2018) and proposing conservation measures.


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