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Trajectories of change in *Posidonia oceanica* meadows and related carbon sink: the ECOSINK project

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Abstract: *Posidonia oceanica* seagrass meadow withdrawal due to human activity and climate changes is evidenced at Mediterranean scale. These meadows are deemed important as carbon sinks but little information is available. The aims of the ECOSINK project are **(i)** to understand the long-term dynamics of the meadows associated with past climate changes in the North-western Mediterranean; **(ii)** to quantify the withdrawal of the lower limit of the meadows during the last decades; and **(iii)** to assess the consequences of the loss of meadows in terms of loss of carbon stored within living *P. oceanica*, and especially the consequences of the loss of carbon sequestrated over millennia within the *P. oceanica 'matte'* (blue carbon), once its protection by living parts of the plant has been removed. The study area corresponds to the NW Mediterranean Sea, including Spain, France and Italy. The ECOSINK project is divided into 3 work packages (WPs), involving 8 partners from France, Italy, Spain and United-Kingdom: WP1 (Long term evolution of *P. oceanica* meadows' lower limit linked to past climate changes); WP2 (Short term evolution of the *P. oceanica* meadows' lower limit linked to human activity) and WP3 (Trajectories of change in *P. oceanica* carbon stocks linked to future climate change).

Introduction

For decades, global change has been evidenced in the Mediterranean Sea: temperature increase [1], acidification [2], higher frequency of extreme events [3], sea level rise [4], loss of biodiversity [5], thermophilic and/or invasive species [6, 7], and the resulting community shift [8]. The impact on indigenous communities and ecosystems is still poorly understood. Primary production and ecosystem services of seagrass ecosystems are among the most highly rated compared to those of other ecosystems [9, 10, 11]. *Posidonia oceanica*, a seagrass endemic to the Mediterranean Sea, forms extensive meadows from the sea surface to 20-40 m depth and has been considered to be the seagrass species with the highest blue carbon storage capacity [12, 13]. The structure constituted by live and dead parts of rhizomes and roots, together with the sediment which fills the interstices, is called '*matte*'. Sediment trapping and orthotropic rhizome growth result in the rise of the *matte* and therefore of the seabed over time [14]. Extensive regressions of *P. oceanica* meadow have been documented during the 20th century, related to the effects of the anthropogenic pressure due to urban, industrial and touristic activities (coastal development, pollution, anchoring, trawling, invasive species, etc.). *Posidonia*

oceanica conservation is required and issupported by EU directives (Natura 2000, Water Framework Directive, Marine Strategy Framework Directive) and international conventions (Bern, Barcelona), and the species and/or the habitat are protected in France, Spain and Italy [15, 16].

Technological progress has enabled the mapping of almost all NW Mediterranean *P. oceanica* meadows [17, 18, 19]. Since the 1980s, *Posidonia* Monitoring Networks (PMNs) have been established along NW Mediterranean coasts. PMNs consist of permanent markers (PMs) fixed along the upper and lower limits of the meadows [20, 21, 22, 23]. More than 1 000 PMs have enabled the precise monitoring of the meadow location and its pattern of change over time. PMNs are currently showing general withdrawals of the lower limit, not only in disturbed areas, but also in pristine areas [23, 24]. Understanding the processes involved in the regression is critical to measure the effective loss of meadow surface area over the last decades and to assess the potential future patterns of change. The goals of the ECOSINK project are **(i)** to understand the long-term dynamics of the meadows associated with past climate changes in the North-western Mediterranean; **(ii)** to quantify the withdrawal of the lower limit of the meadows during the last decades; and **(iii)** to assess the impact of the loss of meadows in terms of loss of carbon stored within living *P. oceanica* and especially the impact of the loss of carbon sequestrated over millennia within the *P. oceanica 'matte'* (blue carbon), once its protection by living parts of the plant has been removed.

Project framework

The project is divided into 3 Work Packages (WPs).

WP1. Long term (centuries-millennia) changes of *P. oceanica* lower limit, in relation to past climate changes:

Dead *matte* (roots and rhizomes), beyond (offshore) the current lower limit of the living meadows, will be sampled at its surface to date the meadow death using ^{14}C analysis (~30 sites with 3 samples per site, following a depth gradient beyond the seaward side of the current limit). This dating will provide a basis for understanding its kinetic and causes.

WP2. Short term (20-30 years) changes in the *P. oceanica* lower limit in relation to human activities:

We propose to visit 50 sites with at least 10-year old PMs of the lower limit of the meadows to measure the descriptors selected by the consortium (distance of the markers from the present limit, depth and type of limit, health descriptors, percentage cover of invasive species, etc.), giving valuable information regarding the dynamics of the lower limit. The causes of the withdrawal (if observed) will be analysed, comparing results from WP1 and WP2 with human pressure per study site. The incidence of global change, if any, will stand from this analysis, considering possible synergistic effects of human induced impacts and environmental conditions.

WP3. Trajectories of change in *P. oceanica* carbon stocks linked to future climate change:

The *matte* represents a huge carbon sink that plays a significant role in limiting the greenhouse effect. While the regression of meadows could moderately affect the carbon stock, the reduction in *P. oceanica* surface areas induces a decline in new sequestration and concomitant mitigation of climate change. In addition, the stock of carbon stored over millennia within the matte constitutes a kind of 'time-bomb': in areas where *P. oceanica* dies and the leaf canopy disappears, the underlying *matte* is no longer protected against erosion; dismantling of the matte will increase organic matter remineralisation rates and return the carbon stored into the environment in the form of carbon dioxide, thus accelerating climate change in a similar way to fossil fuels [13]. We propose to test new remote sensing methods based on seismo-acoustic devices to assess the *matte* thickness. Remote sensing methods will be calibrated (ground truth, penetrometry, coring). This approach has strong potential with a view to understanding the past, present-day and future contributions of *P. oceanica* to the ocean carbon budget, highlighting its resilience in climate change scenarios.

Localization

The project is focused on the NW region of the Mediterranean Sea. The study area will include the coastal domains of Spain (Catalan coast), France (the whole of the Mediterranean coastline, including Corsica) and Italy (Sicily, Liguria). In WP1 and WP2, the study sites will be selected according to:

(i) The presence of existing devices that consist in permanent markers (PMs) of the lower limit of the *P. oceanica* meadow.

(ii) Devices should have been installed for at least 20 years, if possible. Otherwise, 10-year old devices will also be considered.

(iii) It must be possible to sample dead matte of *P. oceanica* beyond (offshore) the present lower limit of the living meadow.

In WP3, previous data are available for almost all study sites from various different acoustic devices [12, 25] (Pergent, unpublished data), located in: north and south Catalonia, Provence, eastern Corsica (a very extensive meadow, > 22 000 ha, with a thick *matte*) and the west coast of Sicily.

Expected results and perspectives

The ECOSINK project will allow the processing of existing data and the setting of a new baseline at basin scale. The consortium partners will provide data, already published or not, derived from the monitoring of *P. oceanica* meadows: localization and state of PMs at the lower limit, patterns of change in the meadow surface area, recent and accurate seabed maps of the study areas, recent data including the use of acoustic devices for *P. oceanica* survey (mapping, *matte* thickness), etc.

The scientific interest of the ECOSINK project is multifold. It will provide data to enhance understanding of the role of living *P. oceanica* in climate change mitigation based on both new carbon storage and retention of the long-term sinks that have been accumulated for millennia [13]. The close interaction between international experts on the *P. oceanica* meadow, with a multidisciplinary approach at regional scale, will offer an opportunity to share skills and data on common activities. The project will enhance the application of existing devices and the revival of long term monitoring programs that had been abandoned by local managers. Priceless data on recent and historic patterns of change in the *P. oceanica* meadow will be available. Trajectories of change in *P. oceanica* in the global change context (linked with IPCC climate models) will be predicted, providing data on the regression mechanisms of *P. oceanica* meadows (the impact of human activities, natural events and climate change). Innovative techniques from geophysics applied to conservation issues will be implemented.

The project will provide knowledge on the ability of the *P. oceanica* meadow to mitigate climate change and on the scope for conservation of these meadows at sites where the major losses are detected (management of both seagrass meadows and carbon stocks). On the basis of the assessment of *matte* thickness, we will provide essential information for the management of the carbon stocks that contribute to mitigating the impact of climate change. Project outcomes will highlight the importance of the conservation of seagrasses in southern and eastern parts of the Mediterranean Sea. This knowledge can be exported to other Mediterranean areas where much of this information is missing. This project is unique in the sense that the study area is the only one that possesses so many permanent markers (PMs) at the lower limit and the type of information that we will obtain can also be exported from the Mediterranean Sea towards areas which are also experiencing a major decline of the meadows [26, 27, 28].

The estimation of the decline of *P. oceanica* surface area over the last decades will eventually be converted into an assessment of the economic shortfall of the natural capital arising from the loss of ecological goods and ecosystem services that meadows provide for the benefit of humans [11].

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