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Operationalizing blue carbon principles in France: methodological developments for *Posidonia oceanica* seagrass meadows and institutionalization

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1 **Operationalizing blue carbon principles in France: methodological developments for**
2 ***Posidonia oceanica* seagrass meadows and institutionalization**

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6 **Highlights**

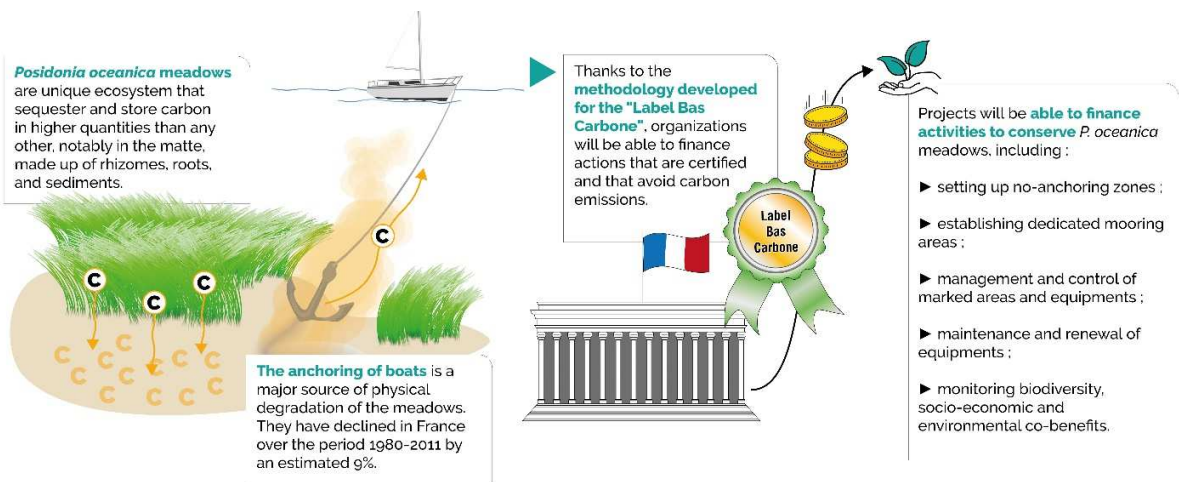
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8
 - 9 • Blue carbon methodologies are interesting tools to finance conservation
 - 10 • The first institutional blue carbon methodology in Europe is described
 - 11 • France has high potential to develop blue carbon projects
 - 12 • Expansion of methodologies should rest on precautionary principles

13
14 **Abstract**

15
16 Conservation of ecosystems is an important tool for climate change mitigation. Seagrasses,
17 mangroves, saltmarshes and other marine ecosystems have particularly high capacities to
18 sequester and store organic carbon (blue carbon), and are being impacted by human activities.
19 Calls have been made to mainstream blue carbon into policies, including carbon markets.
20 Building on the scientific literature and the French voluntary carbon standard, the '*Label Bas-*
21 *Carbone*', we develop the first method for the conservation of *Posidonia oceanica* seagrasses
22 using carbon finance. This methodology assesses the emission reduction potential of projects that
23 reduce physical impacts from boating and anchoring. We show how this methodology was
24 institutionalized thanks to a tiered approach on key parameters including carbon stocks,
25 degradation rates, and decomposition rates. We discuss future needs regarding (i) how to
26 strengthen the robustness of the method, and (ii) the expansion of the method to restoration of
27 seagrasses and to other blue carbon ecosystems.

28
29
30 **Keywords:** Blue carbon, *Label Bas-Carbone*, *Posidonia oceanica*, Marine conservation,
31 ecosystem services, Carbon markets

32
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34 **Graphical Abstract**



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1. Introduction

Atmospheric concentration of greenhouse gases (GHG) continues to rise. Urgent action is needed to mitigate climate change and stay within the objectives defined in the 2015 Paris Agreement of the United Nations Convention on Climate Change, to limit global warming to less than 2°C by the end of the century and as close as possible to 1.5°C (Dimitrov, 2016; UNFCCC, 2016). The loss of biodiversity is another global challenge, which is linked to the issues of biological invasions, coastal development, overexploitation, and climate change (Boudouresque & Verlaque, 2005; Maxwell *et al.*, 2016; Boudouresque *et al.*, 2023; Pörtner *et al.*, 2023). Both issues are driven by human activities, and solutions need to address both threats at the same time.

Nature-based solutions are an important set of options to respond to both global challenges. Nature-based solutions are defined by the International Union for the Conservation of Nature as a set of measures to manage, conserve, and restore ecosystems in order to deal with societal challenges. Measures associated with management and conservation of ecosystems could provide around one third of the necessary reduction in atmospheric GHG by 2030 (Roe *et al.*, 2021). Coastal and marine ecosystems represent an important source of solution to address climate change (Gattuso *et al.*, 2018, Macreadie *et al.* 2021) while carbon fixation and sequestration by European and Mediterranean forest decrease due to climate evolution, fire forest and human use (Chuine *et al.*, 2023; Vallet *et al.*, 2023).

Coastal ecosystems (mangrove, salt meadows, seagrass beds, kelp forests) and terrestrial ecosystems (marshes, peat bogs) represent an important lever. These so-called blue carbon ecosystems store carbon in biomass and sediments under anaerobic conditions over millennia. Thus, their degradation - in addition to destroying unique ecosystems - causes a significant loss of carbon stock. Among other things, it has been estimated that GHG emissions from the degradation of these coastal ecosystems represent between 0.1 and 1.46 GtCO₂ per year, or up to 12% of the CO₂ emissions from annual global deforestation (Howard *et al.*, 2017). They are particularly productive ecosystems since coastal vegetation represent a sequestration equivalent to half of the carbon stock in ocean sediments despite a small surface area (0.5% of the ocean surface area) (Nellemann *et al.*, 2009; Fourqurean *et al.*, 2012). Marine magnoliophytes, *i.e.*

70 seagrasses, play a major role since they are responsible for 40% (50 106 tC yr⁻¹) of the carbon
71 stored each year by coastal vegetation (Nellemann *et al.*, 2009). Finally, they are particularly
72 productive ecosystems from the carbon point of view, under anaerobic conditions that strongly
73 slow down the degradation of biomass into carbon dioxide (Pendleton *et al.*, 2012).

74
75 The conservation (passive restoration through decreased human impacts) and active restoration
76 of blue carbon ecosystems are recognized as one of the tools to mitigate climate change by
77 policy-makers and managers (Macreadie *et al.*, 2021), providing important value for society
78 (Bertram *et al.*, 2021). Several states include blue carbon ecosystems in their Nationally-
79 Determined Contributions (Gallo *et al.*, 2017; Arkema *et al.*, 2023; Herr & Landis, 2016). The
80 Intergovernmental Panel on Climate Change (IPCC) has also produced guidelines for countries
81 to account for their blue carbon (Hiraishi *et al.*, 2014).

82
83 Market-based mechanisms, and particularly carbon markets, are promising tools for financing
84 the conservation and restoration of blue carbon ecosystems (Pergent *et al.*, 2019; Vanderklift *et*
85 *al.*, 2019; Friess *et al.*, 2022; Macreadie *et al.*, 2022; *et alet*). While nature climate solutions
86 could cover around a third of mitigation needs by 2030 (Griscom *et al.*, 2017; Roe *et al.*, 2021),
87 it receives only 3% of global finance. Common rules on cooperation to achieve climate action,
88 including through carbon markets, have recently been determined within the Article 6 of the
89 Paris Agreement. Outside of climate policies and requirements, voluntary carbon markets are
90 flourishing, with almost 2 billion US\$ of value in 2021 (Forest Trends' Ecosystem Marketplace,
91 2022) and a growing demand for blue carbon (Friess *et al.*, 2022).

92
93 There are very few existing methodologies on blue carbon for the voluntary carbon markets. At
94 the international scale, several standards have developed methodologies to account for blue
95 carbon. The Clean Development Mechanism (CDM) has developed one on mangroves (AR-AM
96 00014) with projects in Senegal and Indonesia, Verra organization (Verified Carbon Standard)
97 has produced two methods, the 'VM007' on reducing emissions from deforestation and forest
98 degradation, including wetlands (Verified Carbon Standard, 2020), and the 'VM0033' on tidal
99 wetland and seagrass restoration (Verified Carbon Standard, 2021), with certified mangrove
100 restoration projects in Pakistan. Others exist like microscale project Mikoko Pamoja in Kenya
101 certified by Plan vivo. At the national level, to the best of our knowledge, only Japan and the
102 United States of America (USA) have produced blue carbon methodologies. The methodologies
103 focus on the protection and restoration of seagrasses and macroalgae at the local and national
104 scales in Japan (Kuwae *et al.*, 2022). In the USA, the methodologies focus on restoration of
105 wetlands under the American Carbon Registry (Sapkota & White, 2020).

106
107 In France, the government has set-up its own standard to certify voluntary carbon projects, called
108 *Label Bas-Carbone* (LBC - low carbon label). This standard was introduced in 2018 by the
109 French government. It is administered by the Ministry of Ecological Transition, and has
110 approved thirteen methods so far, mostly dedicated to agricultural lands and forests. Since 2018,
111 the LBC has certified 628 projects, which amount to 2.2 million potential tCO_{2e}.

112
113 Within the LBC, two methods are focused on blue carbon ecosystems. The first one, on the
114 protection of *Posidonia oceanica* meadows, has been approved officially in April 2023. The
115 second method, on the restoration of mangroves and wet forests, is under development and is

116 scheduled for publication before the end of 2023. The remaining of this article will focus on the
117 description of the former.

118

119 There are many types of seagrass meadows in the world and in France (86 species at this day in
120 Guiry & Guiry, 2023). The present method is dedicated to *P. oceanica* meadows only, located on
121 the French Mediterranean coast. These seagrass beds play an important role in mitigating climate
122 change, thanks to their high capacity to capture, sequester and store carbon over millennia. *P.*
123 *oceanica* meadows are unique in this respect: they are the type of seagrass that sequesters the
124 most carbon in the long term, notably in the *matte* (Pergent *et al.*, 2012; Boudouresque *et al.*,
125 2016; Pergent-Martini *et al.*, 2021; Monnier *et al.*, 2022). This below-ground formation, reaching
126 several meters in thickness, is made up of rhizomes, roots and various organic debris clogged
127 with sediment (Serrano *et al.*, 2012; Monnier *et al.*, 2021).

128

129 *Posidonia oceanica* is protected in France under the French Nature Protection Act of July 10,
130 1976, by the decree of July 19, 1988 on the list of protected marine plant species; it is mentioned
131 in the Bern Convention, and since 1999 in Annex II of the Barcelona Convention's Protocol
132 concerning Specially Protected Areas and Biological Diversity in the Mediterranean, and finally
133 in the Council of Europe's 1992 "Habitats-Fauna-Flora" Directive (Directive 92/43/EEC of May
134 21, 1992, amended by Directive 97/62/EEC) (Boudouresque & Bianchi, 2013).

135

136 Despite their protection status, *P. oceanica* meadows are subject to multiple pressures, including
137 in marine protected areas (MPAs) where numerous past or authorized human activities have led
138 to the loss of around 10% of their surface area in the Mediterranean basin over the last 100 years
139 (Boudouresque *et al.*, 2009; Dunic *et al.*, 2021). These seagrass meadows are subject to physical
140 impacts from a variety of sources as coastal development, trawling, anchoring, turbidity, erosion,
141 beach nourishment (Boudouresque *et al.*, 2009; Deter *et al.*, 2013; Holon *et al.*, 2015). The
142 anchoring of pleasure boats, via moorings, is a major source of physical degradation of the
143 meadows (Ganteaume *et al.*, 2004; Cossu *et al.*, 2006; Deter *et al.*, 2017; Pergent-Martini *et al.*,
144 2022a). Thus, *P. oceanica* showed a decline in France over the period 1980-2011: 9% according
145 to Telesca *et al.* (2015), a value that may be overestimated (Boudouresque *et al.*, 2021).

146

147 The aim of this article is to present the process of operationalizing and institutionalizing blue
148 carbon principles within a methodology applicable for the LBC standard in France. The
149 development of this method should result in the enhancement and preservation of a stock of
150 carbon sequestered within seagrass beds and in the process of being degraded, thanks to
151 additional projects improving the abiotic and ecosystem conditions of *P. oceanica* seagrass beds
152 in the Mediterranean. The method describes all the criteria for eligibility, additionality, the
153 consideration of risks associated with general and climatic uncertainties, and the procedures for
154 estimating net reductions in greenhouse gas emissions from projects aimed at protecting
155 *Posidonia* meadows. The method will enable project promoters to obtain funding by
156 implementing and monitoring actions that result in the preservation of carbon stocks threatened
157 by the degradation of the storage environment.

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160 **2. Material and methods**

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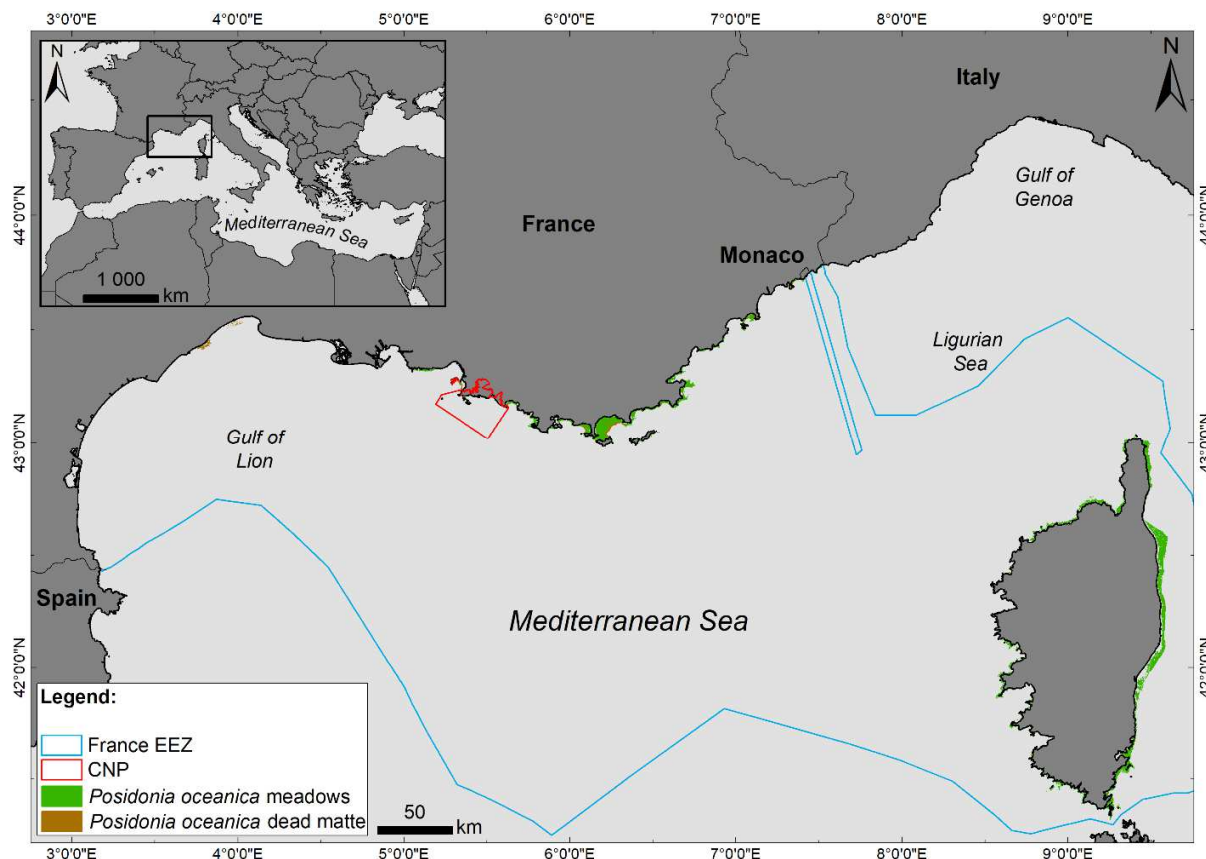
162 **2.1 Literature review**

163 In order to produce a robust and operational carbon accounting methodology for *P. oceanica*
164 seagrass meadows protection, a literature review of published and grey literature was conducted.
165 This literature review fed into an iterative process of methodological development, with a team
166 writing the methodology and a tool for the accounting of projects, feedbacks from discussions
167 with the *Parc National des Calanques* (Calanques National Park, western Provence, France) on
168 their operational needs and constraints, and with the scientific committee that gave expert
169 opinion on the items developed in the methodology and provided additional literature.
170

171 To produce a methodology that meets scientific robustness while aiming for cost-effectiveness, a
172 tiered approach is used for the different parameters that make up the accounting guidelines. The
173 tiered approach follows in its principle the guidelines developed by the IPCC (Hiraishi *et al.*,
174 2014) but tailors it to the specificities of the LBC and of the protection of *P. oceanica* seagrasses.
175

176 **2.2 Case study in Calanques National Park**

177 Marine protected areas are important solutions to address climate change mitigation and
178 adaptation (Roberts *et al.*, 2017; Jacquemont *et al.*, 2022). In order to test and inform the
179 development of the methodology, a partnership was developed with the Calanques National Park
180 (CNP) (Figure 1). The CNP was established in 2012. It covers 8 500 ha on land and 43 500 ha on
181 sea. The high frequentation of its sites leads to impacts on seagrasses, so that the development of
182 methods for the protection of *Posidonia* seagrass meadows could directly bring resources to
183 contribute to decreasing anthropogenic pressures and protection of seagrass carbon stocks. The
184 CNP is in the process of designing no-go zones for boats and dedicated mooring areas, in several
185 of its locations.
186
187
188



189
 190 Figure 1: Distribution of *Posidonia oceanica* seagrass meadows and dead *matte* located in the
 191 Mediterranean region of the French Exclusive Economic Zone (EEZ), and location of the
 192 Calanques National Park (CNP) within it. Data of *P. oceanica* seagrass meadows and dead *matte*
 193 are retrieved from Office Français de la Biodiversité (2023).
 194

195 196 3. Results

197 198 3.1 Projects characteristics

199 The duration of a *P. oceanica* meadow protection project is 10 years, renewable twice, *i.e.* 30
 200 years. The calculation of Emission Reductions (ER) generated by the project will be carried out
 201 over 10 years. All the project owner's commitments are based on a 10-year period, renewable
 202 twice, in line with the duration of the temporary use agreement for the maritime public domain in
 203 France (*Autorisation d'occupation temporaire*).

204 Eligible actions under this methodology concern any project to protect *P. oceanica* meadows,
 205 located in mainland France, and involving the elimination or reduction of impacts linked to
 206 anchoring in *Posidonia* meadows.
 207

208 The anchoring of boats in *P. oceanica* meadows is a major physical pressure, causing bundle
 209 tearing, *matte* degradation, and preventing recolonization over long periods (Ganteaume *et al.*,
 210 2005; Lloret *et al.*, 2008; Boudouresque *et al.*, 2012; La Manna *et al.*, 2015; Abadie *et al.*, 2016;
 211 Deter *et al.*, 2017). Eligible *Posidonia* meadow protection activities are thus associated with the
 212 reduction of impacts linked to anchoring and mooring by:

- 213 - setting up no-anchoring zones,
214 - the establishment of dedicated mooring areas, including the necessary preparatory technical
215 studies,
216 - relative management and control of marked areas and equipment,
217 - maintenance and renewal of the equipment installed,
218 - management of payment systems for use of the mooring areas.
219 Whatever activities are put in place, they must reduce the impact on the meadows by managing
220 and maintaining them over time, at least for the duration of the project.
221

222 **3.2 Additionality**

223
224 To be eligible, projects must show their additionality in terms of regulatory, financial, and
225 common practice dimensions, to be able to claim that they would not have been able to come to
226 fruition without carbon finance. Projects need to go beyond regulatory obligations. Regulations
227 protecting seagrass beds do exist but lack the means to be effective. Projects to protect seagrass
228 beds by implementing management and protection measures that go beyond regulations, by
229 preventing recreational boaters from damaging this ecosystem, by financing the establishment of
230 mooring areas and no-go zones, as well as monitoring, surveillance and knowledge enhancement
231 programs, could be considered additional.
232

233 Projects must not be financially viable. The protection of *P. oceanica* meadows is not a direct
234 revenue-generating activity, even though the ecosystem services they provide to society are
235 estimated at several tens of thousands of Euros per hectare (Rigo *et al.*, 2021). The proposed
236 management plans therefore rely solely on public funds or royalties linked to the commercial
237 and/or recreational use of these areas. In particular, the project developer must demonstrate that
238 the project is economically unfavorable, by studying the possibilities of user fees and public
239 financing, as well as the costs of implementing and maintaining the anchorage areas, to ensure
240 that the project is additional and therefore eligible for carbon finance. Only few anchoring
241 management and mooring zones projects have been implemented so far, thanks to several factors
242 including small size of the system, funding possibilities via MPAs status, proximity to a port
243 facilitating collection of fees, proximity to the beach facilitating collection of fees. An economic
244 model is required to be eligible. The project owner can rely on the demonstration of financial
245 additionality with a Net Present Value analysis to prove that the project is not financially viable
246 without additional carbon financing.
247

248 **3.3 Environmental integrity**

249
250 Projects to protect seagrass meadows can generate co-benefits on biodiversity, socio-economic,
251 and water dimensions (Table 1). These can be integrated in the Monitoring, Reporting, and
252 Verification (MRV) of the project to generate premiums and add value to the project for
253 potential voluntary buyers.
254

255 Table 1. Description of co-benefits that can be integrated in the project. Note that the “*Posidonia*
256 *oceanica* rapid easy index” and the “Biotic index using the seagrass *Posidonia oceanica*” are
257 *water quality indices, not biodiversity indices*
258

Type	Description	Indicator
Biodiversity	Protected species	Number of protected species inventoried
Biodiversity	Habitats rich in biodiversity	Ecosystem-based quality index (Personnic <i>et al.</i> , 2014; Boudouresque <i>et al.</i> , 2015, 2020)
		<i>Posidonia oceanica</i> rapid easy index (Gobert <i>et al.</i> , 2009)
		Biotic index using the seagrass <i>Posidonia oceanica</i> (Lopez y Royo <i>et al.</i> , 2010)
Biodiversity	Active restoration	Number of <i>Posidonia</i> cuttings or surface area restored
Biodiversity	<i>Banquette</i> of dead leaves on beaches	Volume of <i>banquette</i>
Socio-economic	Low-impact mooring systems	Number of ecological moorings put in place
Socio-economic	Fish nurseries function	Fish abundance and richness monitoring
Socio-economic	Public communication on conservation	Number of hours dedicated to communication
Socio-economic	Jobs and trainings	Number of jobs and trainings created
Socio-economic	Offshore beaconing and signage system	Number of systems installed
Socio-economic	Landscape	Reduced visual impact of moorings on landscape (Verlaque <i>et al.</i> , 2023)
Water	Removal and recycling of waste	Percentage of waste removed and recycled from site
Water	Water quality	Monitoring of water quality

259

260

261

3.4 Treatment of risks and uncertainties

262

263 Projects will need to incorporate the risk of general and climatic uncertainties, *i.e.* the risk of
 264 unforeseen carbon emissions due to sources of environmental disturbance such as storms, sea-
 265 level rise or other man-made pressures (*e.g.* macro-waste, dumping at sea, lost fishing gear). The
 266 degradation of seagrass beds is multifactorial, stemming from other sources of disturbance in
 267 addition to the impacts of anchoring. In particular, there are many anthropogenic pressures to
 268 consider, such as the risks associated with macro-waste discharged by boats, or fishing gear,
 269 which are major sources of seagrass degradation (Ruitton *et al.*, 2021). Unfortunately, these are
 270 difficult to quantify, predict or control.

271

272 The effects of rising sea levels linked to climate change are manifold, and can lead to potential
 273 changes in the distribution of ecosystems (*e.g.* the submersion of the midlittoral algal rim
 274 (*trottoir* of *Lithophyllum byssoides*; Blanfuné *et al.*, 2016), and flooding or high-water levels in
 275 major rivers. Global change is also responsible for the acidification of the marine environment.
 276 Acidification can lead to changes in the functioning of *P.* meadows (Scartazza *et al.*, 2017) and
 277 associated communities (Cox *et al.*, 2015, 2016). The long-term consequences of this
 278 phenomenon have yet to be determined. However, these effects are currently considered
 279 negligible (Boudouresque *et al.*, 2009) in terms of impact on seagrass beds, and no discount will

280 be considered. In addition, sea-level rise could potentially modify the spatial extent of the
281 meadows, in which case the project perimeter will have to be adapted. In fact, deep seagrass beds
282 are directly affected by the reduction in available light due to rising sea levels (Pergent *et al.*,
283 2015).

284
285 The risk associated with general and climatic uncertainties will not be incorporated into the
286 biomass growth models, for reasons of complexity for the project developer. However, the risk
287 linked to general and climatic uncertainties will be considered in the form of a discount for all
288 identified risks of 10% on the emissions reductions generated. Indeed, the LBC standard views
289 this discount as a buffer to pool risk of failure across all projects using this method.

290
291

292 **3.5 Quantification of Emission Reductions**

293

294 **3.5.1 General considerations for the calculation of emission reductions**

295
296

297 Seagrass meadows can be divided into several carbon pools: (i) above-ground living biomass
298 (bundles of living leaves); (ii) below-ground living biomass (surface *matte*: rhizomes and roots);
299 (iii) dead biomass (underlying dead *matte*); (iv) accumulation of dead leaves washed up on the
300 shore (Boudouresque *et al.*, 2017; IUCN, 2021). The various carbon compartments included in
301 the methodology and evaluated include only the dead and living *matte* biomass.

302

303 Above-ground biomass is made up of leaf bundles and the epiphytes that attach to them. The
304 carbon captured (photosynthetic fixation) in this compartment is negligible compared with the
305 carbon stored and sequestered in the *matte* and is therefore not considered in this method. Below-
306 ground biomass is separated into two categories: the superficial *matte* (about 30 cm layer) and
307 the underlying dead *matte*. Apparent dead *matte* (visible on the bottom) results from the
308 disappearance of leaf bundles (canopy), for natural or anthropogenic causes, but it is of course
309 also be present under a living seagrass bed. In these areas of dead *matte*, the carbon fixation and
310 sequestration process are interrupted, but existing carbon stocks are considered stable on the time
311 scale of projects eligible for this method.

312

313 The natural washing up and deposition of *P. oceanica* leaves on the coast created structure called
314 *banquettes*. Among other things, this process naturally protects the coastline, stores carbon in the
315 short term (a few months to a few years), and supports biodiversity (a specific food web)
316 (Boudouresque *et al.*, 2016, 2017; Boudouresque & Perret-Boudouresque, 2023). As these
317 *banquettes* are protected, regulations prohibit their removal unless a specific exemption is
318 granted. Despite these benefits and regulatory protection, they are often considered a source of
319 nuisance for operators local authorities, who often decide to remove them (Boudouresque *et al.*,
320 2017). Local authorities claim they do it at the request of users, which is totally contradicted by
321 all users' surveys (Boudouresque *et al.*, 2022). In the present methodology, it was decided to not
322 consider the allochthonous carbon sequestered in these *banquettes*, due to the different
323 temporality of the carbon present compared to other compartments. Indeed, the degradation of
324 fallen leaves is variable. However, the co-benefits associated with activities on these *banquettes*
325 are considered in the method.

326
 327 The emission reductions considered correspond to the difference between the reference scenario
 328 (in which the seagrass beds continue to be degraded by anchoring) and a project scenario (in
 329 which the seagrass beds are preserved by the necessary developments, and their proper
 330 management over time). Emissions reductions will therefore be calculated using the following
 331 formula:

$$332 \quad EER_{i-j} = (1 - Discount_1 - Discount_2 - Discount_3) * \Delta CO_{2i-j}$$

333
 334
 335
 336 Where:

- EER_{i-j} Effective Emission Reductions between year i and year j, in tCO_{2e}
- $Discount_1$ Discount due to general risks on permanence of carbon stocks
- $Discount_2$ Discount due to uncertainties on the Tier 1 generic value of carbon stored in the *matte*
- $Discount_3$ Discount due to the uncertainties on the duration of projects beyond 30 years
- ΔCO_{2i-j} Difference in carbon stocks in the *matte* between year i and year j, in tCO_{2e}

337
 338
 339 The formula for calculating the difference in carbon stock in the *matte* between year i and year j
 340 of the project is:

$$341 \quad \Delta CO_{2i-j} = (CO_{2project}(j) - CO_{2reference}(j)) - (CO_{2project}(i) - CO_{2reference}(i))$$

342
 343
 344
 345 Where:

- $CO_{2project}(n)$ Carbon stock in the *matte* in the project scenario in year n, in tCO_{2e}
- $CO_{2reference}(n)$ Carbon stock in the *matte* in the project scenario in year n, in tCO_{2e}
- j Final year of the monitoring period
- i Initial year of the monitoring period (year 0 for the first verification period)

347
 348
 349 **3.5.2 Reference scenario**

350
 351 The reference scenario is the continuation of practices observed in the project area prior to its
 352 implementation, *i.e.* the perpetuation of seagrass degradation by anchoring. In this scenario, the
 353 carbon stored in the *matte* will be released into marine water bodies and/or the atmosphere
 354 through the detachment and remineralization of organic matter immobilized on the seabed as a
 355 result of repeated anchoring in the same area. To achieve this, three parameters need to be
 356 assessed by the project developer including the surface area of seagrass in the project zone, the
 357 quantity of carbon stored in the *matte*, and the rate of degradation, which combines regression of

358 the seagrass beds (the surface area affected by abrasion from anchoring) in the project area and
359 decomposition of the *matte* (the depth of carbon localized in the *matte* affected).

360

361 These three parameters are found in the following equation:

362

$$363 \quad CO_{2reference}(n + 1) = CO_{2reference}(n) * (1 - T_{regression\ ref} * T_{decomposition})$$

364

365 Where:

366

$T_{regression\ ref}$ Annual rate of regression of seagrass meadows in the project zone, in %

$T_{decomposition}$ Decomposition rate of the carbon stock in the seagrass meadow, in %

367

368 And at the beginning of the project (year = 0):

$$369 \quad CO_{2reference}(0) = A_{seagrass} * C_{matte} * \frac{44}{12}$$

370

371 Where:

372

$A_{seagrass}$ Surface area of seagrass meadows in the project zone at the beginning of the project,
in hectares (ha)

C_{matte} Carbon stock in the seagrass meadows *matte* in the project zone, in tC ha⁻¹

373

374

375 To determine the carbon stock in the *matte*, a tier logic is available to project developers. They
376 can either use simple but conservative default data (Tier 1, Tier 2) or carry out more detailed
377 analyses, which will require more effort but may provide better results (Tier 3). The data to be
378 used for this method are as follows.

379

380 Tier 1: Use of a default value of 327 tC ha⁻¹ (Monnier *et al.*, 2022), considering a *matte* thickness
381 of 1 m (Mateo *et al.*, 2019). Although carbon density (g C cm⁻³) is lower in the first 5 cm of dead
382 *matte* than in living *matte* (Piñeiro-Juncal *et al.*, 2021), the values observed between these two
383 types of *matte* follow the same trend within the first meter of sediment. The same values will
384 therefore be taken into consideration for both categories. Given the uncertainties associated with
385 these default values and to incentivize project owners to use Tier 2 and 3 values, a discount rate
386 of 10% applies if the project developer chooses to use Tier 1 to assess the carbon stock in the
387 *matte*.

388

389 Tier 2: Use of a default value of 1 m *matte* thickness likely to be degraded by anchoring, coupled
390 with the use of local values of estimated C density in *matte* to determine carbon stock in tC ha⁻¹
391 (Romero *et al.*, 1994; Mateo *et al.*, 1997; Mateo *et al.*, 2010; Serrano, 2011; Serrano *et al.*, 2011;
392 Serrano *et al.*, 2012; Monnier, 2020). *Matte* density can be derived from *in situ* data using a
393 standard protocol such as Howard *et al.* (2014) or IUCN (2021) (see SPM1).

394

395 Tier 3: Use of carbon stock data for each category (living and dead *matte*) from a local peer-
 396 reviewed study or *in situ* data using a standard protocol among Howard *et al.* (2014) or IUCN
 397 (2021) (see SPM1). If carbon stock data cannot be obtained in dead *matte* at the local scale,
 398 values obtained in live *matte* will be applied. *Matte* thickness can be measured according to the
 399 protocol established by Monnier *et al.* (2021).

400
 401 The regression of the seagrass corresponds to the surface area of the seagrass that decreases due
 402 to the abrasion of the anchor chains. To determine the regression rate, $T_{regression\ ref}$, a tier logic
 403 is also proposed to the project developer, given the disparities in regression values observed
 404 (Boudouresque *et al.*, 2009). No discount is associated with this parameter. The data to be used
 405 for this method are as follows.

406
 407 Tier 1: Use of a default regression rate of 0.29%. Value taken from the publication by Telesca *et*
 408 *al.* (2015), which provides a summary for the Mediterranean region and assigns a 9% regression
 409 rate for France between 1980 and 2011, *i.e.* an average annual regression rate of 0.29%.

410
 411 Tier 2: Use of data from the anchoring surface on seagrass beds and the abrasion surface caused
 412 by anchoring.

$$T_{regression\ ref} = \frac{(x * 0,016)}{A_{seagrass}} * 100$$

413
 414
 415 Where:

- 416 $A_{seagrass}$ Surface area of seagrass meadows in the project zone at the beginning of the project,
 417 in hectares (ha)
- 418 x Number of boats anchoring in the project zone per annum

419
 420
 421 The abrasion surface depends on both anchoring depth and boat size. In this methodology, the
 422 average value of 160 m² (0.016 ha) will be considered for estimating the abrasion surface of the
 423 chain used by anchored pleasure craft. This result is derived from catenary curve calculations
 424 and considering a 45° oscillation circle, for seven depth ranges (Griffiths *et al.*, 2017).

425
 426 Tier 3: Use of data from a local peer-reviewed study or standardized methods to assess seagrass
 427 regression due to anchoring, taking into account the type of boat, the type of anchor, the type of
 428 chain and their locations on the seagrass beds.

429
 430
 431 The decomposition rate of seagrass beds represents the carbon in the *matte* that is decomposed
 432 due to the repeated action of anchors. To calculate this rate, two tiers are proposed. There is no
 433 discount associated with this parameter.

434
 435 Tier 1: Using the results of the linear model developed as part of the LIFE Blue Natura project
 436 (Mateo *et al.*, 2019) estimating carbon loss in the first meter of *matte* as a result of mechanical

437 degradation due to the repeated action of dredging chains. Additional mechanical erosion also
438 occurs.

439
440
441

$$442 \quad T_{decomposition} = \frac{(100 - (-1,42(n) + 103,5))}{100}$$

443
444 With n the number of years of the project duration.

445
446

447 Tier 2: Use of data from a local peer-reviewed study or standardized methods to assess the
448 decomposition of carbon stock in seagrass beds due to anchoring.

449
450

451 **3.5.3 Project scenario**

452

453 The project scenario is the scenario in which the protection actions are implemented as part of
454 the project. In order to guarantee monitoring of the carbon stock and the state of the seagrass
455 beds over the duration of the project, it is necessary to monitor and verify certain parameters in
456 the ER calculations. These parameters can be found in the following two equations:

457

$$458 \quad CO_{2project}(n) = A_{seagrass} * C_{matte} * \frac{44}{12}$$

459
460

461 And

462
463

$$464 \quad CO_{2project}(n+1) = CO_{2project}(n) * (1 - T_{regression project} * T_{decomposition})$$

465
466

467 With regard to the regression rate, this method proposes monitoring using a tiered approach
468 identical to that described in the previous section. This rate is called $T_{regression project}$, as
469 opposed to the $T_{regression ref}$ of the reference scenario. Note that the choice of Tier for the project
470 scenario must be the same as for the reference scenario. The Tier 1 of the regression rate
471 calculation is a default value equal to zero.

472
473

474 For Tier 2 of the regression rate: Monitoring of the seagrass surface ($A_{seagrass}$) and the number
475 of boats anchoring in the project area will be carried out using data from recognized scientific
476 data online platforms. It will be necessary to justify the robustness of the source mobilized (by
477 explaining the methodology considered, the level of uncertainty, etc.).

478
479

480 For Tier 3: monitoring of seagrass regression must be based on data from a local peer-reviewed
study or the use of standardized methods. These methods should use the sensors and field data
presented in SPM1. The measurement tools to consider include optical sensors for surface data
(e.g. aerial imagery from satellite and/or drone) combined with acoustic sensors for deeper data

481 (e.g. multibeam echo-sounders - MBES, side-scan sonar - SSS), and/or permanent systems
482 positioned on the seabed (e.g. concrete markers, permanent squares, geo-localized photos,
483 cameras). For Tier 3, regardless of the option used, field data must be collected to validate sensor
484 data (e.g. underwater dives). Finally, the decomposition rate is the same for the project and for
485 the reference scenarios.

486
487

488 **3.6 Monitoring, reporting and verification**

489

490 The monitoring of project activities and its impacts on seagrass carbon stocks is conducted by
491 the project developer throughout the project. In order to generate ERs, third-party audits are
492 carried out at least every five years. The purpose of verification is to show that the promised
493 actions have been implemented and that the level of follow-up has been respected. The
494 verifications will be based on the documents provided by the project developers and by on-the-
495 ground field work. These dispositions should allow transparent and accurate accounting of the
496 carbon stocks protected by the project, to minimize the overestimation of ERs produced by the
497 project.

498
499

500 **4. Discussion**

501

502 **4.1 Operationalization**

503

504 The method developed here for the French voluntary carbon market answers one of the main
505 hindrances to investments in blue carbon, which is the lack of robust methods to estimate blue
506 carbon stocks and co-benefits (Vanderklift *et al.*, 2019). There is an inherent tension between
507 ensuring integrity of carbon projects and the costs of monitoring, reporting, and verification. In
508 order to ensure the development of projects on the ground, the choice has been made here to
509 produce methods with low costs of MRV. The integrity is ensured via conservative estimates of
510 carbon stocks, and omission of harder to measure carbon fluxes in *Posidonia* seagrass meadows.
511 Other possible options include the use of more precise MRV methods, which then risks
512 increasing costs beyond the price range found in voluntary carbon markets, thus preventing on
513 the ground development of projects. This was the case with the outcome of the Blue Natura
514 project in Spain (Mateo *et al.*, 2019), which developed a solid methodology that required a
515 market price of 900 € per tCO₂, way above any market price found in the world (and above the
516 value of the social cost of carbon).

517

518 **4.2 Institutionalization**

519

520 There is a gap between the funding needed to protect biodiversity and prevent further losses and
521 the actual amount of funding available. Some estimate this gap at 600 to 800 billion US\$ per
522 year (Deutz *et al.*, 2020). In the current situation, public funding is not sufficient to bridge this
523 gap, which leads many to discuss “alternative” or “innovative” finance mechanisms. Voluntary
524 carbon markets are therefore an important source of funding for the protection of biodiversity
525 (Macreadie *et al.*, 2021). However, in situations where buying carbon credits prevent
526 organizations from reducing their own emissions, this new market mechanism could divert

527 money away from climate mitigation (Seyller *et al.*, 2016). At least, this money goes towards the
528 conservation of ecosystems.

529

530 The importance of private sources of funding to fight global environmental challenges is the
531 primary factor that lead France to establish the LBC. The question is why develop its own
532 national standard when other standards exist. This creates the possibility for high transaction
533 costs. However, the way the LBC is designed allows small projects to emerge and provides a
534 transparent ledger where developers and financiers can meet. The possibility to design large
535 programs on blue carbon is limited by the surface area of habitats and by the fragmented
536 management and ownership of these areas, which increases the cost of carbon credits. This
537 method thus can appeal to companies that operate near seagrass meadows in the Mediterranean,
538 for strategic and corporate social responsibility purposes (Vanderklift *et al.*, 2019).

539

540 **4.3 Future research needs**

541

542 Throughout the course of the development of the methodology to account for carbon stocks and
543 protection offered by carbon projects, research gaps have forced us to consider proxy or
544 conservative ways of quantification. In order to improve this methodology (a process which is in
545 principle continuous and supervised by the Ministry in charge of the environment), several
546 scientific developments have been identified on the different dimensions accounted for here,
547 including carbon stocks, regression rate, and degradation rate.

548

549 There is currently no cheap way of measuring the *matte* height over large areas, which requires
550 development in order to improve the accuracy of the values proposed as default, or to decrease
551 the cost of sampling. There are few methods that make the link between boats dimensions and
552 their impacts on seagrass meadows. This impact depends on the type of anchor, the chain, the
553 weight and height of the boat, and the water depth (Abadie *et al.*, 2016; Griffith *et al.*, 2017). Not
554 all boats are equipped with tracking devices, so that monitoring techniques, via cameras, drones,
555 or else, need to be put in place in order to be able to characterize boats anchoring in project areas
556 and better estimate the surface area of seagrass meadows impacted by them. One issue with the
557 current model is the assumption that boats anchor in different locations, but it is possible for
558 different boat to anchor close to each other and have overlapping effects on the carbon stocks
559 (Pergent-Martini *et al.* 2022b). This should be investigated in the future.

560

561 Even less studied is how much carbon is released by this impact. We used an estimation from
562 Mateo *et al.* (2019) that was calculated from one experiment in Spain but needs to be replicated
563 over time and space to reflect more accurately how much carbon is released from repeated
564 anchoring. Furthermore, more complex ecosystem processes, including primary production and
565 pelagic cycles, are left out of the approach taken here but could play a role in the changes in
566 carbon stocks (Mazarrasa *et al.* 2018).

567

568 The cost of monitoring, reporting, and verification is a huge determinant hindering the
569 development of blue carbon projects, due to the need for underwater surveys, the difficulty of
570 using remote sensing at large scale, and the complex determinants of carbon stocks and fluxes.
571 Ecosystem accounting is now gaining traction, since the approval as an accounting norm of the
572 System of Environmental Economic Accounting – Ecosystem Accounting (SEEA-EA) in 2021

573 by the United Nations (Edens *et al.*, 2022). Marine ecosystems are still under studied in the
574 context of ecosystem accounting (Comte *et al.*, 2022), but development is under way in order to
575 better map marine ecosystem extent and condition (Kervinio *et al.*, 2023), and fluxes of
576 ecosystems services including carbon (Montero-Hidalgo *et al.*, 2023). Ecosystem accounting
577 thus offer a way to systematically account for marine ecosystems and their carbon stocks and
578 fluxes.

579
580

581 **4.4 Future developments of methods on blue carbon**

582

583 Active seagrass restoration activities (replanting, transplanting) are not eligible under this
584 method. Experiments are currently underway, notably the RENFORC project (Université de
585 Corse-GIS Posidonie), as well as the REPAIR (Stareso-Université de Liège) and REPIC
586 (Andromède océanologie) projects, and will contribute to a better understanding of the
587 effectiveness of these actions and their impact on carbon storage and sequestration. The aim is to
588 produce a best practice guide on active restoration (Boudouresque *et al.*, 2021). A specific
589 methodology incorporating these new elements could be developed in the future.

590

591 Many blue carbon ecosystems can be found in France, outside of *Posidonia* seagrass meadows.
592 In the Economic Exclusive Zone, other seagrasses, macro-algae, and salt marshes thrive. The
593 French oversea territories, particularly the Caribbean islands of Guadeloupe and Martinique,
594 French Guyana, and Mayotte, are home to mangrove forests and seagrass meadows that provide
595 important ecosystem services, including climate mitigation (Trégarot *et al.*, 2021). The need for
596 restoration and protection of these ecosystems, and the current lack of coverage of highly
597 protected MPAs, call for innovative mechanisms. The extension of the *Label Bas Carbone*
598 standard to methods applicable to these ecosystems is thus an interesting possibility to explore,
599 and is indeed underway with the development of a method on mangrove restoration and of a
600 method on *Zostera* seagrass meadows restoration.

601

602 **4.5 Precautionary on methods and carbon markets**

603 There are many criticisms around these types of methodologies. On the one hand, the carbon
604 removal using coastal and marine ecosystems has been qualified as uncertain and unreliable
605 (Williamson & Gattuso, 2022). We agree that the underlying processes of fixation and
606 sequestration are still far from being known and accounted for in an exhaustive way (Johanssen
607 and Macdonald, 2016). In this method, we disregard carbon fluxes for this reason, and only
608 account for carbon stocks in the *matte*. On the other hand, avoided emissions (protecting
609 standing stock) are being criticized widely, because the counterfactuals are never easy to produce
610 which undermines the claim that projects are additional (Gillenwater *et al.*, 2007). Against this
611 criticism, the method developed here is very conservative on the type of impacts taken into
612 account and on the degradation rate that is used for the counterfactual, which greatly limits the
613 risk of overestimating the carbon gains from projects using this method. Main issue for
614 *Posidonia* seagrasses is indeed protection of the current carbon stocks, as they took hundreds of
615 years to form, and restoration is slow and costly.

616

617 Several avenues for modifications exist to improve the efficiency and robustness of the French
618 LBC standard. First, the standard allows for anticipatory generation of emission reduction, that

619 has been used in several methodologies, including on forest restoration. This option is risky as
620 several things can happen to carbon stocks in these projects. A precautionary approach would
621 suggest not being able to claim anticipatory emission reductions, which we use in this
622 methodology. We therefore suggest to the Ministry for an Ecological Transition to modify its
623 LBC standard in order to allow only ex-post accounting of emission reductions. Second, major
624 events that can impact carbon stocks along the project life cycle should be better monitored and
625 accounted for via a stronger buffer of carbon emission reductions. Third, there are high
626 transaction costs in developing specific methodologies for the French territories while such
627 methods already exist in international standards. Stronger connections should be made in order to
628 adapt at low cost existing international methodologies to the LBC.

629
630 Lack of control and of satisfactory accounting method could lead to overestimation and
631 undermine the fight against climate change by allowing polluters to offset without actual climate
632 benefits (Johannessen and Macdonald, 2016). Here, this threat is unlikely as the Label Bas
633 Carbone is in dire need of projects as new regulation requires several French economic sectors,
634 including energy and aviation, to buy LBC emission reductions in addition to other stringent
635 policies that aim at reducing emissions from these sectors (EU ETS, ban of short distance
636 flights). In other settings, this risk is however not excluded and should be carefully considered
637 when designing carbon markets (Gillenwater *et al.*, 2007).

638
639

640 **5. Conclusions**

641
642 Thanks to an iterative process including methodology developers, scientific committee, on the
643 ground experts (staff from the Calanques National Park) and support from the Ministry in charge
644 of the environment, the first methodology on the protection of *P. oceanica* seagrass for the
645 French voluntary carbon market has been developed and approved. This methodology uses a
646 tiered approach to balance scientific robustness and cost of monitoring of carbon stocks and
647 project activities. The method takes careful consideration of the problematic issues of carbon
648 offsetting methodologies, including additionality, integrity, and monitoring.

649
650 We hope that many project developers and financiers will take up this method to put in place
651 protection measures against the negative impacts of anchoring on *P. oceanica* seagrass beds in
652 the French Exclusive Economic Zone. This method could be expanded to other geographies in
653 the Mediterranean region, and to other activities that promote the conservation and restoration of
654 these important marine ecosystems.

655
656
657

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659
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969 **Supplementary material**

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SPM1. Methods available for the monitoring of Posidonia seagrass protection projects. Adapted from UNEP (2015).

Method used in the literature	Key information	Advantages and limits
Acoustic methods		
Side-Scan Sonar	Depth: over -8 m (Clabaut <i>et al.</i> , 2006) Precision: From 0.1 m (Kenny <i>et al.</i> , 2003) Area mapped: tens of km ²	Most used method but difficulties to obtain density and heights. Allows complete coverage of seabed contrary to the multibeam echosounder
Multi-beam echosounder	Depth: Tens of meters (Valette-Sansevin <i>et al.</i> , 2019) Precision: 0.2 m (Komatsu <i>et al.</i> , 2003) Area mapped: from 1 m (Kenny <i>et al.</i> , 2003)	3D images of meadows. High amount of data necessitates efficient computer processing and archiving, and complex data processing
Optical methods		
Aerial photos	Depth: from 0 to -20 m but more adapted from 0 to -10 m Precision: from 0.2 m (Frederiksen <i>et al.</i> , 2004) Area mapped: Small surface areas (10 km ² ; in Diaz <i>et al.</i> , 2004) but can also be used for large areas (100 km ²)	Image precision can be adapted depending on objective (Pergent <i>et al.</i> , 1995) Manual interpretation possible, direct and easy. Sizeable images library with access to chronological series.
Satellite imagery	Depth: from 0 to -20 m but adapted from 0 to -10 m. Technique in progress with visibilities to deeper areas (Traganos & Reinartz, 2018). Precision: from 0.5 m Area mapped: Few km ² to large surface areas (more than 100 km ²)	Usable everywhere without authorization high geometric precision. Possibility to find free access low resolution images.

Drone imagery	Depth: 0 to -15 m Precision: very high spatial resolution Area mapped: From 0.1 m	Low cost and high flexibility in terms of deployment and customization. High quality and resolution
Field work		
Dives	Most accurate method to describe and identify benthic communities (Bianchi <i>et al.</i> , 2004)	Limited operational time and depth (Parravicini <i>et al.</i> , 2010)
Permanent square		
Cameras	Depth: whole bathymetric tranche Precision: from 0.1 m (Kenny <i>et al.</i> , 2003) Area mapped: Adequate for small area	Non-destructive method, easy to use. Possible to store the images.
Seismic methods		
Seismic reflection	Allows representation of sedimentary layers. Useful to estimate the thickness of the <i>matte</i> and carbon stocks at large scales but does not give information on the health of the seagrass meadows. Non-destructive method.	

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