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# Ecosystem-based assessment of a widespread Mediterranean marine habitat: the Coastal Detrital Bottoms, with a special focus on epibenthic assemblages

1 **Patrick Astruch<sup>1\*</sup>, Ameline Orts<sup>1</sup>, Thomas Schohn<sup>1</sup>, Bruno Belloni<sup>1</sup>, Enrique Ballesteros<sup>2</sup>,**  
2 **Daniela Bănaru<sup>3</sup>, Carlo Nike Bianchi<sup>4,5</sup>, Charles-François Boudouresque<sup>3</sup>, Pierre**  
3 **Chevaldonné<sup>6</sup>, Jean-Georges Harmelin<sup>1</sup>, Noémie Michez<sup>7,8</sup>, Briac Monnier<sup>9</sup>, Carla Morri<sup>4,5</sup>,**  
4 **Thierry Thibaut<sup>3</sup>, Marc Verlaque<sup>3</sup>, Boris Daniel†<sup>8</sup>**

5 <sup>1</sup>GIS Posidonie, Aix-Marseille Université, Mediterranean Institute of Oceanography (MIO),  
6 Marseille, France

7 <sup>2</sup>CEAB-CSIC, 17300 Blanes, Girona, Spain

8 <sup>3</sup>Aix-Marseille Université, Université de Toulon, CNRS, IRD, Mediterranean Institute of  
9 Oceanography (MIO), Marseille, France

10 <sup>4</sup>Seascape Ecology Laboratory, DiSTAV (Department of Earth, Environment and Life Sciences),  
11 University of Genoa, Genova, Italy

12 <sup>5</sup>EMI, Department of Integrative Marine Ecology, Stazione Zoologica Anton Dohrn–National,  
13 Institute of Marine Biology, Ecology and Biotechnology, Genoa Marine Centre, Genoa, Italy

14 <sup>6</sup>IMBE, CNRS, IRD, Aix-Marseille University, Avignon University, Station Marine d'Endoume,  
15 Marseille, France

16 <sup>7</sup>Parc naturel Marin du Golfe du Lion, Argelès-sur-mer, France

17 <sup>8</sup>Office Français de la Biodiversité, Brest, France

18 <sup>9</sup> Université de Corse Pasquale Paoli, CNRS UMR 6134 SPE, Campus Grimaldi, Corte, France

19 **\* Correspondence: Patrick Astruch**

20 [patrick.astruch@univ-amu.fr](mailto:patrick.astruch@univ-amu.fr)

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27 1 Supplementary Figure

28 **Abstract**

29 Coastal detrital bottoms (CDB) are one of the most extensive habitats of the continental shelf  
30 worldwide, in the upper levels of the circalittoral zone. Hosting a diverse community structured by  
31 sediment grain size, trophic interactions and rhodoliths, bryozoans and other calcified organisms, CDB  
32 play important ecological functions. In the Mediterranean Sea, CDB are constituted by recent elements  
33 partly provided by adjacent infralittoral (e.g., rocky reefs and *Posidonia oceanica* meadows) and  
34 circalittoral (e.g., coralligenous reefs) ecosystems. Since the 2010s, the offshore extension of many  
35 Marine Protected Areas (MPAs) has substantially incorporated vast areas of CDB, and at the same time  
36 raised the issue of their management. Until recently, studies focused on CDB have mainly dealt with  
37 infauna, taxonomy and rhodolith beds, while very few have considered global functional aspects.  
38 European Directives such as the Habitats Directive (HD), the Water Framework Directive (WFD) and  
39 the Marine Strategy Framework Directive (MSFD) aim at maintaining or improving the ecological  
40 status (ES) or conservation status of water bodies and habitats. The MSFD has embraced the concept  
41 of an ecosystem-based approach to consider the functioning of marine habitats and their related  
42 ecosystem services provided as new indices for managers. The purpose of this paper is to propose an  
43 ecosystem-based quality index (EBQI) tested on CDB from the north-western Mediterranean Sea,  
44 focusing mainly on epibenthic assemblages. The first step has been to define a conceptual model of the  
45 CDB functioning, including the main trophic compartments and their relative weight, then to identify  
46 appropriate assessment methods and potential descriptors. Twenty-nine sites were sampled along the  
47 coast of Provence and French Riviera (South France) with SCUBA diving and a purposely designed  
48 device, the 'Biocube'. Study sites were chosen in order to encompass a wide range of hydrological  
49 conditions and human pressures. We observed very different ES driven by local natural features and  
50 human activities. Very well-preserved sites were found in Provence in areas without trawling and  
51 terrigenous inputs, while impacted and low-ES sites were located in the vicinity of urbanized areas.  
52 The cover of Corallinales, Peyssonneliales and Sporolithales qualifies the seascape and might be an  
53 indicator of the good ecological status of CDB and reduced human pressure. However, the absence of  
54 rhodolith association may also be induced by natural phenomena. The EBQI designed for CDB proved  
55 representative and useful for a functional assessment based on epibenthic assemblages. Robustness of  
56 status and weighting of the compartments were tested. However, some descriptors have shown their  
57 limitations and should be further explored for a proper assessment, bearing in mind that effective  
58 indices should be quick and easy to apply. We highlight here the issue of establishing an index  
59 corresponding to a societal demand (e.g., European directives, Barcelona convention) to lead to a broad  
60 and large-scale assessment based mainly on the seascape and epibenthic assemblages, for practical and  
61 operational reasons. We stress the need to extend this index over a wider geographical scale,  
62 particularly to the southern and eastern Mediterranean Sea sectors, which are highly affected by the  
63 spread of non-indigenous species. The applicability of this index to extra-Mediterranean locations  
64 should also be considered.

65 **1 Introduction**

66 Coastal detrital bottoms (CDB), sometimes also called coastal (bio-)detritic bottoms in the literature,  
67 are soft bottoms composed of mineral and biogenic particles, characterized by a distinct structural  
68 complexity hosting soft sediment infauna together with epifauna and epiflora settled or not on coarser  
69 granules (Rees, 1999). Often regarded in the past as an inconvenient mixture escaping the classical  
70 dichotomy between rock and sediment biotopes (Jones, 1950), they are today considered as a  
71 distinctive biotope in the circalittoral zone of the continental shelf worldwide (Pérès, 1982; Konar et  
72 al., 2006; Amado-Filho and Pereira Filho, 2012; La Rivière et al., 2021).

73 In the Mediterranean Sea, CDB are one of the most widespread ecosystems between 30 and 100 m  
 74 depth, corresponding to the upper part of the circalittoral zone (Pérès and Picard, 1964; Pérès, 1967),  
 75 and house a high alpha species diversity (Stamouli et al., 2022). Besides a mineral component (typically  
 76 coarse sand with a variable proportion of finer particles), these bottoms contain significant quantities  
 77 of recent organogenic and bioclastic sediments (remains from hard bottoms, shell debris, bryozoans or  
 78 calcified macro-algae), either autogenous or imported from adjacent ecosystems (e.g., coralligenous  
 79 reefs, photophilic rocky reefs, seagrass meadows). Structure and composition of CDB can therefore  
 80 differ depending on adjacent ecosystems and hydrodynamic conditions (Pérès and Picard, 1964; Joher  
 81 et al., 2015; Agnesi et al., 2020). The pelitic proportion (sediment grain  $< 63 \mu\text{m}$ ) of the sediment is  
 82 usually very low, but muddy CDB can be found (Bellan-Santini et al., 1994). Located at the same depth  
 83 range than CDB, Muddy Detrital Bottoms (MDB) are characterized by an important sedimentation rate  
 84 influenced by the terrigenous input from coastal rivers. MDB can be constituted by a compact mud  
 85 including bioclastic shells, muddy sand, or sandy mud (Pérès and Picard, 1964; Picard, 1965; Bellan-  
 86 Santini et al., 1994; Michez et al., 2014; La Rivière et al., 2021). Deep Detrital Bottoms (DDB),  
 87 generally between 80 and 250 m depth, correspond to fossilized detrital sediments from terrigenous  
 88 (fluvial) and bioclastic inputs corresponding to ancient environmental conditions and a lower sea  
 89 level (Pérès and Picard, 1964; Bellan-Santini et al., 1994), covering the deepest part of the continental  
 90 shelf. The sediment is a mix of pebbles, sand and mud but with a mud proportion significantly higher  
 91 than in the CDB. Coarser sediment is made of calcareous remains from thanatocenoses of the  
 92 Pleistocene ice ages (Laborel et al., 1961; Pérès and Picard, 1964; Bourcier and Zibrowius, 1973;  
 93 Michez et al., 2011, 2014). Distinguishing the boundary between CDB and muddy or deep detrital  
 94 ecosystems is sometime challenging.

95 Pérès and Picard (1964) based their description of CDB on the infauna, which contain the most  
 96 characteristic species; however, the same authors and others (Costa, 1960; Joher et al., 2015; La Rivière  
 97 et al., 2021) identified a number of CDB facies on the basis of less characteristic epibenthic species,  
 98 especially macroalgae, either erect or encrusting. The former include perennial and seasonal species,  
 99 such as *Cystoseira* spp., *Ericaria* spp., *Gongolaria* spp., *Osmundaria volubilis*, etc.; the latter are  
 100 represented by the Corallinales *Lithophyllum racemus*, *Lithothamnion corallioides*, *L. crispatum*, *L.*  
 101 *minervae*, *L. valens*, *Neogoniolithon hauckii*, *Spongites fruticulosa*, the Peyssonneliales *Peyssonnelia*  
 102 *crispata*, *P. heteromorpha*, *P. rosa-marina*, *P. rubra*, *P. squamaria*, and the Sporolithales *Sporolithon*  
 103 *mediterranea*, among others (Huvé, 1954; Jacquotte, 1962; Boudouresque and Denizot, 1973;  
 104 Ballesteros, 1994). Free-living calcified macroalgae forming nodules of various morphology, called  
 105 “rhodoliths” (or more specifically “maerl” in the case of branched growth forms), raised a great interest  
 106 among benthic ecologists (Sciberras et al., 2009; Basso et al., 2017; Deidun et al., 2022). Their  
 107 conservation value is recognized under EU rules and international conventions (Barbera et al. 2003;  
 108 Salomidi et al., 2012). Marion (1883), Meinesz et al. (1983) and Holon and Harmelin (2014) described  
 109 a CDB facies with large calcified bryozoans, such as *Pentapora fascialis*, *Smittina cervicornis*,  
 110 *Turbicellepora avicularis*, *Hornera* spp., etc. But the highest diversity of bryozoans on CDB is  
 111 represented by numerous and small species (Harmelin, 2017); by analogy with calcareous rhodophytes,  
 112 bryozoan free are called bryoliths (James et al., 2006; Lombardi et al., 2014). This bryozoan facies is  
 113 classified as a priority habitat according to the Barcelona Convention (Bianchi, 2009a). Recently,  
 114 coralloliths formed by the scleractinian coral *Cladocora caespitosa*, also considered of conservation  
 115 interest (Morri et al., 2000; Bianchi, 2009b), have been described from coarse sandy bottoms in the  
 116 Balearic Islands (Kersting et al., 2017a, 2017b). Several octocoral species, such as *Eunicella singularis*,  
 117 *E. verrucosa*, *Leptogorgia sarmentosa*, *Alcyonium palmatum*, *Pennatula rubra*, *Pteroeides griseum*  
 118 and others, may also form epibenthic facies on detrital seabeds (Morri et al., 1991). Fauna and flora  
 119 associated to all these epibenthic facies are sometimes very similar to coralligenous assemblages  
 120 (Ballesteros, 2006; Pergent et al., 2015). The EUNIS typology defines Coralligenous platforms These

121 are coralligenous horizontal formations developing within sedimentary beds subject to currents, at up  
122 to at least 100 metres depth in clear waters. These formations are not usually built on rock substrata  
123 but result from the active development of constructor organisms (e.g. calcified algae, hard-skeleton  
124 invertebrates) from scattered elements on loose beds, shells, stones, and graves (Pérès and Picard,  
125 1965).

126 Important ecological functions and ecosystem services, up to now poorly-evaluated, are provided by  
127 CDB (Ballesteros, 1994; Barbera et al., 2003): (i) primary production (Basso, 2012; Basso et al., 2012),  
128 (ii) key habitat and trophic resources for invertebrates and fish, (iii) breeding, spawning and nursery  
129 grounds for fish and crustaceans including species of fishery interest, sometimes close to the deep limit  
130 of *Posidonia oceanica* meadow (e.g., Mullidae, Sparidae, Scorpaenidae, *Palinurus elephas*) (Harmelin  
131 and Harmelin-Vivien, 1976; Verlaque, 1990; Kamenos et al., 2004; Soykan et al., 2010), (iv) fishing  
132 ground for trawlers and artisanal fishers (Stamouli et al., 2022), (v) long term carbon sink (Basso, 2012;  
133 Basso et al., 2012; Savini et al., 2012; Burrows et al., 2014; Watanabe et al., 2020), (vi) recycling of  
134 necromass (e. g. rhizomes and dead *Posidonia oceanica* leaves and drift macroalgae) (Boudouresque  
135 et al., 2016). In addition, CDB host numerous protected species and other species of conservation  
136 interest (Astruch et al., 2012, 2019; Joher et al., 2015): the fan shell *Pinna nobilis* (annexe II Berne  
137 convention and UICN Red list: critically endangered), the red coralline alga *Lithothamnion*  
138 *corallioides* (Annexe 5 of the HD: species of interest with a regulation of its exploitation), and several  
139 Fucales (Annexe 2 of the Barcelona convention), among others. Management goals on maerl beds are  
140 different in the Mediterranean compared to the rest of the world, where extraction activities are carried  
141 out (Foster et al., 1997, 2013; Steller et al., 2003; Amado-Filho et al., 2017; Harvey et al., 2017).

142 Nowadays, like most coastal biocenoses, CDB are facing human activities and climate change. They  
143 are threatened by numerous pressures (Dutertre et al., 2015; Demestre et al., 2017) such as trawling  
144 (Bordehore et al., 2000, 2003; Fragkopoulou et al., 2021), artisanal or recreational fishing (Rendina et  
145 al., 2020), dredging (De Grave and Whitaker, 1999; Bermejo et al., 2018; Bernard et al., 2019),  
146 terrigenous input, dumping of sediment and waste, fish farming (Sanz-Lázaro et al., 2011; Aguado-  
147 Giménez and Ruiz-Fernández, 2012), consequences of coastal development, sea water warming,  
148 spread of non-indigenous species (Klein and Verlaque, 2009; Katsanevakis et al., 2014; Martin and  
149 Hall-Spencer, 2017; Hall-Spencer and Harvey, 2019) and potentially acidification (Noisette et al.,  
150 2013).

151 Until recently, studies about CDB in the Mediterranean Sea were mainly focused on description of  
152 infauna (e.g., Pérès and Picard, 1964; Picard, 1965; Somaschini et al., 1998), rhodolith beds and  
153 associated communities (e.g., Ballesteros, 1994; Basso et al., 2017), and taxonomy (e.g., Boudouresque  
154 and Denizot, 1973; Souto et al., 2010), without any overview at ecosystem scale (e.g., Gautier and  
155 Picard, 1957; Jacquotte, 1962; Boudouresque and Denizot, 1973; Augier and Boudouresque, 1975,  
156 1978; Laborel et al., 1976; Harmelin, 1978; Bourcier, 1982, 1985, 1988; Fornos et al., 1988; Joher et  
157 al., 2012, 2015).

158 Despite the high ecological and heritage value of CDB and the many threats pending on it, this  
159 ecosystem was not considered as a habitat of European interest (Bensettiti et al., 2004) by the Habitats  
160 Directive of the European Union (Natura 2000, 92/43/CEE) while some facies of CDB are described  
161 in EUNIS typology (Gayet et al., 2018) and considered in Barcelona convention. Recently, the Habitats  
162 Directive has evolved, considering rhodolith beds as a reef habitat (1170) if it host communities  
163 characteristic of hard substrates (De Bettignies et al., 2021). In France, the extension of surface areas  
164 of Marine Protected Area (MPA) (national parks, Natura 2000 sites, etc.), since the 2010s, incorporated

165 large expanses of seabed occupied by CDB. According to these new management issues, it has become  
 166 a challenge to better consider this widespread ecosystem.

167 Even with the improving accuracy of technologies (e.g., side scan sonar, multibeam, remotely operated  
 168 vehicles, autonomous underwater vehicles, etc.) (Bianchi et al., 2004; Astruch et al., 2012; Valette-  
 169 Sansevin et al., 2019) and prediction models (Martin et al., 2014; Vassallo et al., 2018), mapping of  
 170 CDB is still challenging. The evaluation of coastal water body masses, marine habitats or ecosystems  
 171 involves numerous indices with different purposes (Bianchi et al., 2022). None of these indices is able  
 172 to solve all issues: specific descriptors may assess the ecological status linked with water quality  
 173 (WFD; e.g., Ballesteros et al., 2007; Gobert et al., 2009; Lopez y Royo et al., 2010; Blanfuné et al.,  
 174 2017; Piazzzi et al., 2021), ecosystem functioning (descriptor 1 of the MSFD; e.g., Personnic et al.,  
 175 2014; Giakoumi et al., 2015; Montefalcone et al., 2015a), seafloor integrity (descriptor 6 of the MSFD;  
 176 e.g., Montefalcone et al., 2007; Gatti et al., 2015; Enrichetti et al., 2019; Piazzzi et al., 2019), the  
 177 conservation status of natural habitats (HD; e.g., Maciejewski et al., 2016; Sartoretto et al., 2017),  
 178 natural and anthropogenic stressors (Holon et al., 2015; La Rivière et al., 2017; Ruitton et al., 2020).

179 Obviously, the future of coastal zone management is not linked with a unique integrative index (Bond,  
 180 2001), but a consistent combination of the more relevant ones (Pikaver et al., 2004; Paoli et al., 2016;  
 181 Borja et al., 2021; Oprandi et al., 2021). Indicators are currently used to support managers and  
 182 stakeholders' guidelines. In that context, the ecosystem-based approach is to be considered (Laffoley  
 183 et al., 2004; Boudouresque et al., 2020a), aiming at a better understanding of ecosystem functioning  
 184 for a more suitable management. Ecosystem-Based Quality Indices (EBQIs) have been already defined  
 185 for a number of coastal marine ecosystems, namely *Posidonia oceanica* meadows (Personnic et al.,  
 186 2014), coralligenous reefs (Ruitton et al., 2014), undersea caves (Rastorgueff et al., 2015) and rocky  
 187 reefs (Thibaut et al., 2017). The aim of the present work is to develop and apply an original EBQI  
 188 expressly designed for CDB (Astruch et al., 2022a). Although CDB is traditionally identified mostly  
 189 by the study of the infaunal component, which requires sampling with grabs or dredges operated from  
 190 large vessels, the approach presented here will focus on the epibenthic component, which can be  
 191 studied with a light-duty approach, i. e. photo, video and/or visual techniques - to be privileged in a  
 192 conservation context (Bianchi et al., 2022). The adequacy of this novel index was tested along the  
 193 coasts of Provence and French Riviera (France, Mediterranean Sea) (Fig. 2).

## 194 **2 Material and Methods**

### 195 **2.1 Conceptual model of Coastal Detrital Bottom functioning**

196 A workshop gathering 15 experts in benthic ecology (mainly authors of the present work) was held (i)  
 197 to propose and validate a conceptual model of the CDB functioning, (ii) to define the weight of each  
 198 functional compartment (=box) corresponding to its importance in the ecosystem, and (iii) to elaborate  
 199 a sampling protocol with suitable and operational descriptors to assess the different compartments. A  
 200 DELPHI approach was carried out (Rowe and Wright, 1999). The conceptual model thus defined  
 201 schematizes the functioning of CDB (Fig. 1). The compartments of the conceptual model are described  
 202 in the following pages.

### 203 **2.2 Sampling strategy**

204 Twenty-nine sampling sites were investigated (Table 1). Site selection considered different level of  
 205 pressures linked with human activities, from pristine-like to urbanized sites. The study area presents a  
 206 gradient in hydrological conditions, involving the Rhône River at the West, the oligotrophic waters of  
 207 eastern Provence and the run-offs in the urbanized French Riviera.

208 Two depth ranges were sampled at each site: the upper zone (between 28 and 43 m, according to the  
 209 lower limit of the *Posidonia oceanica* meadow), and the deep zone (between 48 and 79 m depth).  
 210 Upper sites were selected far enough away from *P. oceanica* meadows to avoid the transitional zone  
 211 and ensure a correct assessment of CDB compartments.

212 Sampling was carried out by scuba diving, photoquadrats and seascape video. At the upper zone,  
 213 observations were carried out by scuba divers for inventory of *in situ* recognizable taxa and assessment  
 214 of their abundance. Each dive corresponds to the observation of 2 divers during ~12 minutes.  
 215 Considering the movements of the divers at an average speed of 10 m·min<sup>-1</sup> (including stops) observing  
 216 the bottom on a 2 m wide strip, each dive corresponds to an investigated surface area of ~500 m<sup>2</sup>. Three  
 217 cores of sediment were sampled per site to assess organic matter and sediment grain size. At both upper  
 218 and deep zone, an original device, the ‘Biocube’ (Fig. 3), was implemented to sample: (i) photoquadrats  
 219 of an 80 cm × 80 cm sized frame using a compact camera with a 15 s time lapse. On-board video  
 220 monitoring using a GoPro® Hero 3 allowed controlling the position of the quadrat during sampling.  
 221 Each quadrat was randomly positioned according to the drift of the operating boat. (ii) Seascape videos  
 222 were taken during the photoquadrat sampling. The diversity of sampling methods aims at bringing  
 223 complementary observations at the scale of each sampling site for a standardized assessment.

## 224 **2.3 Compartments assessed**

### 225 **2.3.1 Box 1: Rhodoliths: Free living Corallinales, Peyssonneliales, and Sporolithales**

226 This compartment is involved in the structuring of the ecosystem by increasing sediment grain size and  
 227 providing a support for other compartments (see boxes 2, 3, 10 in Fig. 1). Among Corallinales, several  
 228 species can be found such as *Lithothamnion corallioides*. Peyssonneliales can be calcareous or not,  
 229 several species occur in CDB, such as *Peyssonnelia rosa-marina* (Boudouresque and Denizot, 1973)  
 230 or *P. squamaria*. The Sporolithale *Sporolithon mediterraneum* is a frequent rhodolith species of CDB.  
 231 For some species, *in situ* identification is challenging or impossible and collection is needed. The cover  
 232 is naturally decreasing according to depth and the corresponding reduction of light availability. In  
 233 oligotrophic and clear waters, rhodolith beds can found up to 80 m depth (Ballesteros, 1994). Aguilar  
 234 et al. (2009) described rhodolith beds at 140-150 m depth around the Balearic Islands. Rhodoliths play  
 235 an important role in the deep benthic fixing and sequestration of organic and inorganic carbon (Basso,  
 236 2012; Basso et al., 2016). The cover (mean percentage) of living rhodoliths appears to be the easiest  
 237 descriptor to assess the structure of CDB, which conditions its functioning both at the upper and the  
 238 deep zones (Bosellini and Ginsburg, 1971; Basso et al., 2016).

### 239 **2.3.2 Box 2: Perennial non-calcified macroalgae**

240 The abundance of perennial non-calcified macroalgae can be linked to good ecological conditions and  
 241 the absence of significant pressures (mechanical erosion, terrigenous inputs, decrease of light). Fucales  
 242 (*Sargassum* spp., *Ericaria* spp., *Gongolaria* spp., *Cystoseira* spp.), Laminariales (*Laminaria*  
 243 *rodriguezii*), *Osmundaria volubilis* and *Carpomitra costata* are among the most representative taxa  
 244 (Gautier and Picard, 1957 ; Joher et al., 2012; Thibaut et al., 2016; Aouissi et al., 2018; Bermejo et al.,  
 245 2018; Bruno de Sousa et al., 2019; Jódar-Pérez et al., 2020; Reynes et al., 2021). These long-living  
 246 species provide a stand for seasonal macroalgae (boxes 3 and 4) and sessile fauna (box 10), a habitat  
 247 (boxes 9 and 12) and a trophic resource (box 5). They contribute significantly to the primary production  
 248 of the ecosystem. *Codium bursa*, *C. vermilara*, and *Sphaerococcus coronopifolius*, perennial species  
 249 observed during the present work, were not considered. Indeed, the abundance of these species known  
 250 as tolerant can be linked to a stressor (Vidondo and Duarte, 1995; Ruitton et al., 2017). In addition, *C.*

251 *fragile* is a non-indigenous species (Provan et al., 2005). The mean percentage cover at the upper zone  
 252 is a suitable descriptor to assess this compartment.

253 **2.3.3 Box 3: Seasonal erected macroalgae**

254 Macroalgae species from this compartment, characterized by fast growth rate and seasonal cycle, thrive  
 255 mainly from spring for a maximum development during summer. Seasonal macroalgae also contribute  
 256 significantly to primary production. The most frequent and abundant taxa are the Phaeophyceae  
 257 *Arthrocladia villosa* and *Sporochnus pedunculatus*, widespread in the circalittoral both in  
 258 Coralligenous reefs and CDB. Some species usually observed in the infralittoral can be found such as  
 259 *Acetabularia acetabulum* or *Padina pavonica*. *Umbraulva dangeardii* is a Ulvophyceae that can be  
 260 observed often associated with rhodolith beds. *Chrysomenia ventricosa* and *Sebdenia* spp. are among  
 261 the main characteristic Florideophyceae. Identification at species level is impossible based on *in situ*  
 262 observation and video and photographs analysis. The mean cover (percentage) of seasonal macroalgae  
 263 appears to be a suitable descriptor. Non-indigenous and invasive species with a seasonal dynamic can  
 264 thrive in the CDB: *Caulerpa cylindracea* (Klein and Verlaque, 2008), *C. taxifolia* (Meinesz et al., 2001;  
 265 Montefalcone et al., 2015b), mucilage (several species including NIS: *Acinetospora crinita*,  
 266 *Chrysonephos lewisii*, *Nematochryopsis marina*, *Zosterocarpus oedogonium*) (Giuliani et al., 2005;  
 267 Schiaparelli et al., 2007; Bianchi et al., 2019a). The latter taxa have been considered as stressors and  
 268 therefore not taken into account in the assessment of compartment 3.

269 **2.3.4 Box 4: Seasonal turf**

270 Seasonal turf is defined as an algal community with a small height (a few centimetres at most).  
 271 Worldwide, turf is more and more observed replacing more structuring communities, influenced by  
 272 stressors (Littler and Littler, 1980; Connell et al., 2014). Seasonal turfs include numerous species but  
 273 very few can be identified *in situ* like the Ulvophyceae *Pseudochlorodesmis furcellata* and *Valonia*  
 274 *macrophysa*. *Womersleyella setacea* and *Acrothamnion preissii*, two alien species (Boudouresque and  
 275 Verlaque, 2002), can be present and are considered as stressors. These two species are often invasive  
 276 in coralligenous reefs, *Posidonia oceanica* meadows, and infralittoral photophilic reefs (Piazzi and  
 277 Cinelli, 2000; Piazzi et al., 2007; Bianchi et al., 2019b), and were found in CDB of Port-Cros National  
 278 Park (Provence, France; Astruch et al., 2019). The distinction by visual assessment between seasonal  
 279 turf and seasonal erected macroalgae is difficult. Considering that the two compartments evolve with  
 280 the same dynamics, it is relevant to consider their cumulative cover as the descriptor of their status at  
 281 both upper and deep zones. The ‘compartments 3 and 4’ are therefore named hereafter ‘compartment  
 282 3-4’.

283 **2.3.5 Box 5: Herbivores**

284 The important diversity of the macroalgal communities on CDB (boxes 1, 2, 3, 4) influences the  
 285 abundance and the diversity of herbivores. In the present work, the following taxa were considered as  
 286 herbivores: echinids (*Centrostephanus longispinus*, *Echinus melo*, *Sphaerechinus granularis*,  
 287 *Stylocidaris affinis*), and the gastropods *Cerithium* sp. and *Aplysia* spp. While *S. granularis* is strictly  
 288 an herbivore (Weinberg, 1996; Wirtz and Debelius, 2003), *S. affinis*, *C. longispinus* and *E. melo* are  
 289 omnivores. The latter two are not characteristic of CDB, even if they can be found in the vicinity of  
 290 coralligenous beds. According to food availability and habitat (Wilkie et al., 1996), they are able to  
 291 shift into an herbivorous-dominant behaviour (De Ridder and Lawrence, 1982; Francour, 1989, 1991;  
 292 Bergbauer and Humberg, 2000). *S. granularis* and *S. affinis* are known to be seasonally observed  
 293 gathering on detrital bottoms (Harmelin and Duval, 1983). Vertebrate herbivores are mainly  
 294 represented seasonally by the fish *Sarpa salpa* during its breeding period (late summer) (Verlaque,  
 295 1990). Considering the short duration of the phenomenon, this species is not taken into account in this



296 compartment. The alpha taxonomic richness (number of taxa per site) is a relevant descriptor to assess  
297 the herbivores compartment.

### 298 **2.3.6 Box 6: Particulate Organic Matter of the sediment (POM)**

299 Particulate organic matter (POM) of the sediment observed in abundance can be linked to natural  
300 eutrophic conditions or to a stressor (Sciberras et al., 2009). Based on our sampling strategy, the  
301 assessment of this compartment is feasible by considering the cover of muddy sediment on the bottom  
302 observed on the photoquadrats. This descriptor is already applied to assess the POM sedimented on  
303 coralligenous reefs (Ruitton et al., 2017). However, its assessment on CDB proved difficult. We  
304 therefore propose the percentage of pelitic fraction (<63 µm) as a proxy of the POM of the sediment.  
305 Organic matter accumulation is determined by environmental dynamics (currents, fine particles  
306 transfer to deep areas) (Orekhova and Ovsyany, 2020). An important percentage can also correspond  
307 to Muddy Detrital Bottoms (MDB).

### 308 **2.3.7 Box 7: Infauna**

309 Infauna constitutes a key compartment, influenced by sediment grain size and organic matter content  
310 (Pérès and Picard, 1964; Cocito et al., 1990). We distinguished three trophic groups within the infauna:

311 CDB, particularly in the upper circalittoral zone, are characterized by a relatively coarse grain size,  
312 decreasing with depth. It directly influences the trophic network in the sediment. Consequently, coarse  
313 sediment hosts a lower content in organic matter and a lower abundance of the infauna (Blanchard et  
314 al., 2009). According to Bellan et al. (1980), high organic matter content can be a stressor for infauna,  
315 traducing a blocking of the recycling of organic matter by polluted water inputs. The organic matter  
316 content is often used as a descriptor of the trophic status of infauna (Cocito et al., 1990; Dell'Anno et  
317 al., 2002). However, natural abundance of organic matter can be linked to the vicinity of seagrass  
318 meadows, (i) providing dead leaves that partly remain in the sediment, or (ii) with dead matte a few  
319 cm under the sediment surface (Boudouresque et al., 2019). In the present work, we evaluate the whole  
320 infauna compartment from the organic matter content in the sediment (percentage).

### 321 **2.3.8 Box 8: Organic microdetritus**

322 *Posidonia oceanica* seagrass meadows produce and export a huge number of dead leaves to adjacent  
323 ecosystems, including CDB (Boudouresque et al., 2016). Infralittoral photophilous reefs and  
324 coralligenous reefs also export macroalgae, which accumulate or move over circalittoral soft bottoms.  
325 Organic macrodetritus composition and biomass vary according to source ecosystems: dead leaves of  
326 *P. oceanica*, macroalgae or terrestrial plant remains. Before reaching greater depth, off the continental  
327 shelf, organic macrodetritus is used as a trophic resource by the detritivores of the CDB.

### 328 **2.3.9 Box 9: Detritivores**

329 Detritivores play an important role, degrading litter and organic debris on the sediment. This  
330 compartment is composed of Echinodermata (Holothuroidea, Echinoidea and Asteroidea), Crustacea  
331 and Gastropoda. The abundance of some taxa can be favoured by eutrophic (i.e., HOM: High Organic  
332 Matter) or oligotrophic (LOM: Low Organic Matter) conditions. Two categories are distinguished: **(9a)**  
333 **HOM Detritivores:** including *Holothuria* spp., *Bonellia viridis* and Paguridea; **(9b) LOM**  
334 **Detritivores:** represented by *Spatangus purpureus*, *Echinaster sepositus*, Gastropoda and Crustacea  
335 (Mysidacea, Malacostraca). While a high abundance of HOM detritivores can be linked with a CDB  
336 potentially degraded (eutrophication), the abundance of LOM detritivores, more sensitive to

337 eutrophication, indicates a good status of this compartment. Mean density (individuals per m<sup>2</sup> observed  
338 in the photoquadrats at both depth) is a relevant descriptor to assess detritivores 9a and 9b.

### 339 **2.3.10 Box 10: Filter and Suspension feeders**

340 Benthic filter and suspension feeders on CDB belong to various taxonomic groups: Annelida,  
341 Ascidiacea, Bryozoa, Cnidaria, Porifera) (Harmelin, 1978; Souto et al., 2010). On coralligenous reefs,  
342 the abundance of *Cliona viridis* is considered as a consequence of stressors (bioerosion in a eutrophic  
343 configuration) (Cerrano et al., 2001), the presence of *C. viridis* with a relatively low density on CDB,  
344 as observed in our case study, cannot be considered as an indicator of stress. Mean density of  
345 individuals or colonies per m<sup>2</sup> (observed in the photoquadrats at both depths) seems to be the most  
346 suitable descriptor for filter and suspension feeder assessment, unlike taxonomic richness, due to the  
347 problems for *in situ* identification or from videos or photographs.

### 348 **2.3.11 Box 11: Planktivorous teleosts**

349 This compartment includes planktivorous pelagic or demersal fish, with life traits significantly linked  
350 with the substrate. Strictly pelagic planktivorous teleosts with no interaction with the bottom (e.g.,  
351 Clupeidae, Engraulidae) were not considered. The main species observed were *Spicara maena*, *S.*  
352 *smaris*, *Boops boops*, *Chromis chromis* and *Anthias anthias*. The two latter indicate clearly the vicinity  
353 of hard substrates. CDB play an important role for these species: a spawning ground for *Spicara* spp.  
354 (Harmelin and Harmelin-Vivien, 1976) and an essential habitat for *Boops boops* juveniles.  
355 Planktivorous species are also essential in the trophic network providing a food supply for high level  
356 predators (Bănaru et al., 2013; Cresson et al., 2020). The alpha specific richness (number of species  
357 per site, considering all methods) was measured to assess the planktivorous teleosts' compartment.

### 358 **2.3.12 Box 12: Carnivores**

359 This box encompasses all carnivorous species, predators of crustaceans, annelids, fish, sponges and  
360 other benthic invertebrates. This box is divided in two: Invertebrate carnivores (12a) and Vertebrate  
361 carnivores (12b). **(12a) Invertebrate carnivores:** it includes mainly motile species: crustaceans,  
362 echinids (Asteroidea, Ophiuroidea), Gastropoda, Nudibranchia, Cnidaria, etc. The alpha taxonomic  
363 richness of invertebrates carnivorous (per site considering all methods) is a suitable descriptor for this  
364 compartment. **(12b) Vertebrate carnivores:** it gathers teleost fish species (e.g., Pleuronectidae,  
365 Trachinidae, Sparidae, Gobiidae, Blenniidae, Mullidae, Labridae, Triglidae) and chondrichthyans (e.g.,  
366 *Scyliorhinus* spp., Rajidae). Carnivorous fish find an important trophic resource at the surface or inside  
367 the sediment of CDB. Some use CDB as a nursery habitat (e.g., *Serranus hepatus*, *Blennius ocellaris*)  
368 or a breeding habitat (e.g., *Symphodus cinereus*, *Solea* spp.). The assessment of abundance or diversity  
369 of fish assemblages normally applied in other marine habitats, such as reefs or seagrass meadows  
370 (Harmelin-Vivien et al., 1985), proved of little applicability in CDB. The most suitable descriptor to  
371 assess the compartment 12b is the alpha taxonomic richness (number of species observed per site  
372 considering all methods).

## 373 **2.4 Compartments not assessed**

374 In the frame of an ecosystem-based approach, it is necessary to considerer all the main functional  
375 compartments even if some are not assessed.

### 376 **2.4.1 Phyto- and Zooplankton**

377 Together with POM, phytoplankton and zooplankton are the basis of planktivores diet (Khoury, 1987;  
378 Cresson et al., 2014; Chen et al., 2022). This compartment can vary very quickly, and its proper  
379 assessment would require too much time and resources according to its weight in the ecosystem  
380 functioning (Table 1). In the framework of an index assessment, the more suitable is to assess it  
381 indirectly through its consumers, as done for other ecosystems (see Personnic et al., 2014; Thibaut et  
382 al., 2017).

### 383 **2.4.2 Pelagic Dissolved and Particulate Organic Matter (DOM and POM)**

384 Dissolved organic matter (DOM) and particulate organic matter (POM), provided by phytoplankton  
385 exudation, grazing by zooplankton and terrestrial inputs, play a key-role in the marine microbial trophic  
386 network (Mostajir et al., 2012) and in some coastal food webs (Darnaude, 2005; Bănară et al., 2007).  
387 As far as the CDB ecosystem is concerned, this compartment is considered as indirectly assessed by  
388 the filter feeders and suspension feeders' compartment (Box 10) and therefore was not assessed  
389 directly.

### 390 **2.4.3 Microbial loop**

391 The microbial loop is driven by the DOM and the POM (Velimirov et al., 1984). DOM is an important  
392 substrate for bacterial production. The microbial loop is defined as a community gathering  
393 heterotrophic micro-organisms, namely Archaea, bacteria, flagellated eukaryotes and ciliates (Azam et  
394 al., 1983; Boudouresque, 2015). This compartment is not directly assessed in the present work but it is  
395 strictly linked with POM and DOM, plankton communities, filter and suspension feeders (Box 10),  
396 planktivores (Box 11) and carnivores (Box 12).

### 397 **2.4.4 Piscivores**

398 Piscivorous teleosts strictly linked with CDB are very few. High level predators that can be found are  
399 mostly casual visitors from adjacent ecosystems (see below). *Lophius* sp. and *Scorpaena scrofa*, two  
400 nocturnal and benthic predators, occupy more frequently CDB. At the scale of a given sampling site,  
401 the occurrence of piscivores is very low.

### 402 **2.4.5 Visiting (high-level) predators**

403 Numerous high-level predators can visit occasionally CDB, such as *Dentex dentex*, *Pagrus pagrus*,  
404 *Zeus faber*, and feed from planktivorous or mesocarnivorous fish species. Because of a very low and  
405 occasional occurrence, this compartment was not taken into account.

### 406 **2.4.6 Transiting living organisms**

407 Many organisms transit through the CBD mainly from the infralittoral and circalittoral ecosystems to  
408 the bathyal and abyssal bottoms. Consequently, numerous species from coralligenous reefs,  
409 infralittoral reefs and *Posidonia oceanica* meadows can be found in CDB. The assessment of this  
410 transiting fauna was indirect through the main assessed compartments of CDB (Boxes 1, 2, 3-4, 5, 9,  
411 10, 12).

412 **2.4.7 Carbon sink**

413 Rhodolith beds act as major carbon sinks through their high storage capacity of both organic ( $C_{org}$ ) and  
 414 inorganic carbon ( $C_{inorg}$ ). The effectiveness of this role is strictly associated with the vitality of  
 415 calcareous organisms living with these ecosystems (Martin et al., 2007; Basso, 2012; Burrows et al.,  
 416 2014; Watanabe et al., 2020). While the  $C_{inorg}$  sequestration results mainly from the significant calcium  
 417 carbonate contents of rhodoliths skeleton (Van Der Heijden and Kamenos, 2015), the capture and the  
 418 trapping of  $C_{org}$  within rhodolith beds come from autochthonous and allochthonous sources (Mao et  
 419 al., 2020). The  $C_{org}$  production is mainly completed through the photosynthesis of rhodolith organisms  
 420 (B1) and the occurrence of facies of calcareous invertebrates (e.g., Bryozoa, Echinidae, Gastropoda,  
 421 Annelida, Bivalvia). Though the  $C_{org}$  fixation is well known for rhodolith beds (Watanabe et al., 2020),  
 422 its long-term sequestration in the sediments is still to be specified. For *P. oceanica* meadows, the  
 423 fixation and  $C_{org}$  sequestration capacity proved to be highly related with water depth and its state of  
 424 conservation. Thus, healthy and shallow meadows are considered as carbon sinks whereas deeper and  
 425 altered ones may act as carbon sources (Monnier, 2020; Monnier et al., 2021, 2022; Pergent-Martini et  
 426 al., 2021).

427 **2.5 Descriptors selection**

428 Fifteen descriptors were selected to assess the 12 boxes of CDB (Table 2). Boxes 3 and 4 were  
 429 considered together as seasonal macroalgae, so that 11 boxes were actually considered. The weight of  
 430 each box ( $W$ ), defined at first during the workshop, was successively adjusted according to the results  
 431 of the test in the field. The compartments selected to have the main contribution to the functioning of  
 432 the ecosystem are: Box 1-rhodoliths ( $W=6$ ), Box 5-infauna ( $W=5$ ), box 10-filter and suspension  
 433 feeders, Box 2-perennial and Box 3-4-seasonal macroalgae ( $W=4$ ).

434 Descriptors for each compartment were selected among a wide range of available descriptors tested  
 435 during the sampling. The criteria for the descriptor selection were (i) its applicability, (ii) a large  
 436 enough range of values along the sampled sites, (iii) the absence of correlations with the descriptors of  
 437 other compartments in order to reduce the total number of descriptors.

438 The method to assess each descriptor is presented in Table 3. The monitoring of one sampling site can  
 439 be held in less than one day with a small boat and 3 operators. It implies (i) one dive with two operators  
 440 in the upper zone with 12 minutes of investigations (sampling of 3 sediment cores, photographs and  
 441 videos), covering a mean surface of about 500 m<sup>2</sup> and (ii) the implementation of the Biocube at the two  
 442 depths (upper and deep zones) to sample 30 photoquadrats per depth and seascape videos. (iii) Analysis  
 443 of the cores involves measurement of grain size and percentage of organic matter.

444 **2.6 EBQI calculation**

445 The EBQI is then calculated using the following formula:

446 
$$EBQI = \left[ \frac{\sum_{i=1}^{11} (W_i \times S_i)}{\sum_{i=1}^{11} (W_i \times S_{max})} \right] \times 10$$

447  $W_i$  is the weight of the box,  $S_i$  the status of the box and  $S_{max}$  maximum status possible (4/4). A notation  
 448 between 0 and 10 is obtained. An ecological status is defined according to the EBQI notation  
 449 (Personnic et al., 2014; Table 4). The ecological status limits are similar to those defined for *Posidonia*  
 450 *oceanica* seagrass meadow (Personnic et al., 2014), coralligenous reefs (Ruitton et al., 2014) and rocky  
 451 reefs (Thibaut et al., 2017).

452 A confidence index (CI) was used to assess the quality of the data (suitable protocol, recent data, expert  
453 judgment) (see Personnic *et al.*, 2014 for CI calculation) (Table 5). The CI allows assessing the quality  
454 of the sampling according to the recommended methods. If a sampling does not imply all the suitable  
455 methods, it will still be possible to calculate an EBQI with a low CI (e.g., data available with other  
456 protocols, expert judgement).

### 457 **2.7 Statistical analysis**

458 Correlation between descriptors notation has been tested by calculating Spearman rank-order  
459 correlation and assessing its significance with p-value. Principal Component Analysis (PCA) was used  
460 without standardization to show relation between boxes and sites EBQI notations.

461 The robustness of the EBQI for CDB has been tested regarding the ecological status per box and the  
462 weight per box. A robustness analysis involving 1000 simulations with 25, 50, 75 or 100% of  
463 probability of perturbation of  $\pm 1$  or  $\pm 2$  (of each ecological status per box and each weighting per box)  
464 has been tested. The analysis recalculates the EBQI notation considering the corresponding  
465 perturbation ( $\pm 1$  or  $\pm 2$ ) and the probability of perturbation (25, 50, 75 or 100%).

466 Box status have been plotted on radar charts and the uniformity of box status have been assessed  
467 through circularity of polygons representing those charts. Circularity is the ratio between the polygon  
468 area and the area of a circle having equal circumference to the polygon perimeter (Oprandi *et al.*, 2021).  
469 Perimeter and area have been calculated using ArcGIS Pro 3.0®.

470 The influence of the management level was tested on EBQI notations and circularity value using  
471 PERMANOVA analysis, using euclidian distance and 999 permutations (Anderson, 2001).

472 P-value threshold was set at 5% for all tests. Analyses were performed with R software (R core team,  
473 2022).

## 474 **3 Results**

### 475 **3.1 EBQI notation**

476 EBQI notation ranged from 2.05 (27TH) to 8.06 (21PAM) (Table 6). Eight sites out of 29 exhibited a  
477 Good or Very Good notations while 10 a Poor or Bad status. The Confidence CI was reduced on the  
478 box 7 (infauna) for all sites because of the method used (organic matter assessment instead of  
479 macrofauna analysis). The CI was very good for all sites, ranging from 88 to 93 %.

480 EBQI notation and box status attributed to each site are mainly explained by local specificities and the  
481 vicinity or not of human activities (i.e., urbanized areas). PCA showed a gradient along Axis 2 (16.8  
482 % of the total variance) from Poor to Very Good sites. Good and Very Good EBQI notations were  
483 mainly explained by the high status of boxes 1, 2 and 3-4 (primary producers). Boxes 6 (sedimented  
484 POM), 7 (infauna), 8 (organic macrodetritus) and 12 (carnivores) were less discriminating (Fig. 4).

485 Radar plot projection helps assessing the heterogeneity of ecological status per box for each sampling  
486 site (Supplementary Fig. 1). For example, 21PAM (Pampelonne), with the best notation (EBQI = 8.06),  
487 is defined by ecological status ranging from 2 to 4 while 09EMB (Embiez), also with a good notation  
488 (EBQI = 6.98) is characterized by ecological status between 0 and 4.

489 A Spearman rank correlation has been tested between the fifteen descriptors used for EBQI calculations  
490 (Fig. 5). Positive correlations moderately to highly significant are observed between descriptors related

491 to primary producers (Box 1 - rhodoliths, Box 2 - perennial macroalgae, and Box 3-4: seasonal  
 492 macroalgae and turf). These same descriptors also show significant correlations with the mean density  
 493 of LOM detritivores (Box 9b). The diversity of herbivores (Box 5) shows a significant negative  
 494 correlation with the cover of organic macrodetritus (Box 8). The percentage of organic matter (Box 7)  
 495 shows low but significant correlations ( $R^2 < 0.34$ ) with sedimented POM (Box 6). The percentage of  
 496 pelitic fraction of the sediment (Box 6) shows a significant negative correlation with the cover of  
 497 perennial macroalgae (Box 2), rhodoliths (Box 1-UZ) and seasonal macroalgae and turf (Box 3-4).  
 498 HOM detritivores density (Box 9a) shows no correlations with any other descriptor.

### 499 **3.2 Circularity analysis**

500 The circularity of radar charts reflects the uniformity of box status. Values range from 0.25 (28ANT)  
 501 to 0.73 (21PAM) and is independent of the EBQI notation (Spearman correlation:  $R=0.242$  et  $p=0.206$ ).  
 502 According to the EBQI notation and circularity value, 4 different situations are identified (Fig. 6): (i)  
 503 CDB sites with moderate-good notation ( $EBQI \geq 5$ ) and high homogeneity of box status (circularity  $\geq$   
 504 0.5) like 24DRA, 04PLA, 09EMB, 16BAG and 21PAM; (ii) CBD sites with moderate-good notation  
 505 but low homogeneity of box status like 13FG, 18CAV, 15HB, 20CAM, 26EST, 24PQR and 17 VAI;  
 506 (iii) CBD sites with poor notation ( $EBQI < 5$ ) and high homogeneity of box status status like 22ST,  
 507 10AMP, 07 CC and 29VIL; (iv) CBD sites with poor global notation and low homogeneity of quality  
 508 status like 27TH, 01COU, 06SUG, 11DF, 05PR, 25AGA, 03PRA, 02CAR, 12TGR, 28ANT, 23SAR  
 509 and 19CT.

### 510 **3.3 Influence of the Management level**

511 The management level on the 29 sampling sites is heterogeneous. We can distinguish 4 levels: (i) No  
 512 protection (4 sites), (ii) Natura 2000 with no effective protection (12 sites), (iii) protected, including  
 513 MPA with a Multi-Use Management (MUM) (5 sites) (iii) highly protected, including MPA with No-  
 514 Take Zone (NTZ) (8 sites). Analysis of EBQI mean notation and Circularity mean value per  
 515 management level shows no significant differences between management level (Permanova:  
 516 respectively  $p=0.866$  and  $0.737$ ; Fig. 7).

### 517 **3.4 Robustness analysis**

#### 518 **3.4.1 Robustness regarding perturbation of the ecological status**

519 The higher is the perturbation and the probability of perturbation, the less similarity is observed in the  
 520 iterations compared to the initial EBQI calculation (Fig. 8; Supplementary Table 1). The percentage of  
 521 similarity decreases with the probability of perturbation or the number of perturbations ( $\pm 1$  or  $\pm 2$ ).  
 522 When perturbing the ecological status per box, the mean similarity (all sites included) evolves from  
 523 81.8% (25%) to 61.7% (100%) for a  $\pm 1$  perturbation and from 68.8% (25%) to 38.8% (100%) for a  $\pm 2$   
 524 perturbation. A high perturbation of the ecological status implies a lower stability of the EBQI.

#### 525 **3.4.2 Robustness regarding perturbation of the weighting**

526 When perturbing the weighting per box, the mean similarity is higher, moving from 91.5% (25%) to  
 527 84.5% (100%) for a  $\pm 1$  perturbation and from 86.5% (25%) to 73.3% (100%) for a  $\pm 2$  perturbation  
 528 (Fig. 9; Supplementary Table 1). The perturbation of the weighting does not affect the stability of the  
 529 index as much as the perturbation of the ecological status per box.

530 The lower values of similarity for high levels of perturbation ( $\pm 2$ ) of both the ecological status per box  
 531 and the weighting confirm the fact that weighting the boxes is consistent and useful, as already shown

532 by Personnic et al. (2014) for *Posidonia oceanica* seagrass meadows. It is worth noting that the sites  
533 with the lowest similarity are often the sites which initial EBQI notation is close to a threshold between  
534 two statuses (e.g., 7.53 is a very good notation but very close to the good status < 7.50).

## 535 4 Discussion

### 536 4.1 An original Ecosystem-Based Quality Index for the Coastal detrital bottoms

537 This paper proposes an original Ecosystem-Based Quality Index to assess the health status of the  
538 Coastal Detrital Bottoms in the North-western Mediterranean context. The goal is to provide (i) a useful  
539 tool, embracing the ecosystem-based approach concept, for coastal managers (MPAs, local  
540 authorities), and (ii) arguments for a better consideration of this key habitat according to the MSFD  
541 and Barcelona Convention. To define a relevant biological indicator, the main issue is finding the  
542 balance between the most suitable descriptors versus the feasible methods according to available  
543 human and material resources. Unlike ecosystem of priority interest such as *Posidonia oceanica*  
544 meadows (Montefalcone, 2009; Lopez y Royo et al., 2010; Personnic et al., 2014; Oprandi et al., 2021),  
545 very few indices or descriptors are available for CDB functional or ecosystem-based analysis.

546 EBQI is a suitable tool to assess broadly the functioning of an ecosystem (Boudouresque et al., 2020a,  
547 2020b). It aims at providing a first integrated insight with a general notation and status per  
548 compartments, useful at the scale of a sampling site or in the frame of a monitoring network at larger  
549 scale. The CI for CDB, between 88 to 93%, is by far higher than the mean CI assessed for sites where  
550 other EBQIs indices were defined: 53% for *Posidonia oceanica* seagrass meadows (Personnic et al.,  
551 2014), 62% for undersea caves (Rastorgueff et al., 2015), and 74% for rocky reefs (Thibaut et al.,  
552 2017).

553 Our analysis put in evidence the influence of both natural features and anthropogenic activities on the  
554 ecological status of CDB. Sites in areas without trawling or dredging activities, far from urbanization  
555 show the best notation. The Provence and French Riviera coast provides a large gradient of  
556 anthropogenic pressure and local natural specificities. This heterogeneity was the key for defining an  
557 EBQI for CDB and testing the reliability of the descriptors of the functional compartments. A further  
558 analysis will benefit of new and detailed data to identify the causes of such a status: natural feature  
559 (hydrological context, geology, adjacent habitats) or pressures linked with human activities (trawling,  
560 terrigenous input, coastal development, etc.). As for all point measurement methods to assess the  
561 ecological quality, EBQI needs a high number of replicates per site to give a better insight into the  
562 structure of the ecosystem assessed. This approach aims at offering a broader view of the ecosystem  
563 functioning.

564 According to our results, the protocol proposed is accurate, using feasible methods by scuba diving,  
565 photographs, photoquadrats and videos. The robustness analysis showed an effect of a perturbation of  
566 the ecological status per box or weighting. Nevertheless, the percentage of similarity remained high  
567 for a relatively moderate perturbation. The probability of 25% was tested to simulate a theoretical  
568 application with one in four chances of being wrong, which is consistent and closer to the reality of  
569 field application. Keeping in mind that the EBQI aims at a broad assessment of ecosystem quality and  
570 functioning, the results confirmed the robustness of the approach.

### 571 4.2 Critics and improvement perspectives

572 It would have been relevant to assess properly the macrofauna of the sediment instead of organic matter  
573 measurement (Box 7), which would have improved the quality of the assessment, at ecosystem scale,

574 but increasing the time-consumption of the sampling. The index AMBI (AZTI's Marine Biotic Index:  
 575 Borja et al., 2000, 2003), applied for the Water Framework Directive, allows the assessment of the  
 576 ecological status of soft bottoms based on the macrofauna of the sediment. It considers the abundance  
 577 in the sediment of species sensitive to stressors, tolerant and opportunist. It can give good and reliable  
 578 information about infauna status to complete and improve the ecosystem-based assessment. The  
 579 macrofauna of the sediment is of importance in terms of ecological functioning and trophic interactions  
 580 with epibenthic and demersal communities (Austen et al., 2002), and obviously, an assessment  
 581 considering only the organic matter content is far from being enough (Cocito et al., 1990). It could also  
 582 be argued that while the proper identification of CDB must be based on the infauna (Pérès and Picard,  
 583 1964), the index here presented focuses mostly on the epibenthos. However, characterization and  
 584 evaluation are two distinct steps of environmental diagnostics (Bianchi et al., 2012): evaluation criteria  
 585 can be applied only after the habitat in question has been characterized. We do believe that the health  
 586 status of the CDB epibenthic facies is an acceptable proxy for the quality of the whole ecosystem; that  
 587 is why we have decided to assign the highest weighting to the Box 1 (Rhodoliths), which could be  
 588 discussed. All the direct anthropogenic physical pressures mentioned in the previous pages obviously  
 589 threaten epibenthos first, rather than infauna; and as far as we know, also the ongoing seawater  
 590 warming is affecting epibenthic species more than the infauna (Cerrano et al., 2000; Garrabou et al.,  
 591 2009). But it may be true that the degradation of the CDB epibenthic facies may not necessarily imply  
 592 a bad status for the infauna, and further research is needed.

593 Rhodolith beds from CDB can be considered both soft and hard substrata, according to its benthic  
 594 communities (Jacquotte, 1962; Hall-Spencer, 1998; Basso et al., 2017). Rhodolith beds are also  
 595 described as a step towards the edification of coralligenous banks, from a soft bottom towards a hard  
 596 bottom, in specific environmental conditions (Basso et al., 2007). The pioneer zoologist André Fortuné  
 597 Marion named 'coralligenous gravels' the rhodolith beds of the Gulf of Marseille (Marion, 1883). The  
 598 '*Coralligène de plateau*' described by Laborel (1961), Pérès and Picard (1951, 1964) and Bellan-  
 599 Santini et al. (1994) is a coralligenous bank developed from the growing and coalescence of rhodoliths.  
 600 It highlights the key-role of calcareous macroalgae in inducing autogenic ecological succession  
 601 (Laborel, 1961; Laubier, 1966; Odum, 1971; Begon et al., 1976; Basso et al., 2007). In some  
 602 circumstances, the epibenthic associations of the CDB, particularly rhodolith beds, can be considered  
 603 at the threshold between a circalittoral sandy bottom and an actual upcoming coralligenous bank. A  
 604 CDB facies with small concretionary boulders has also been described (Meinesz et al., 1983). This  
 605 does not mean that CDB should be equated to a hard substrate. The slow evolution towards a  
 606 coralligenous bank can not be generalized to all CDB, even in presence of rhodolith beds.

607 Bryozoan facies, as described by Bianchi (2009a) and Harmelin (2017), have not been found in the 29  
 608 sampling sites considered in the present work. The patchiness of epibenthic associations and facies and  
 609 the rarity of such a feature might explain our result. Yet, *Pentapora fascialis* facies are known for  
 610 example around Port-Cros Island (Holon and Harmelin, 2014; Harmelin, 2017) but were not found  
 611 during our investigations. Such rarity increases the conservation issue and the importance of protecting  
 612 and monitoring CDB. Bryozoans are known to contribute significantly to the bioclastic part of soft  
 613 bottoms worldwide (Halfar et al., 2006).

614 The assessment of widespread and patchy habitat such as CDB requires a seascape approach. It is  
 615 known that the seascape can influence directly the trophic network and the ecosystem functioning  
 616 (Boström et al., 2011; Abadie et al., 2018; Santos et al., 2022). In that consideration, a seascape  
 617 approach should be a potential suitable descriptor to assess the quality of an ecosystem (e.g., marine  
 618 forests, habitat structure, etc.; Cheminée et al., 2014; Thiriet et al., 2014). We have proposed a  
 619 combination of methods to provide a large and as representative as possible assessment, involving



620 direct observation via scuba diving, photoquadrats and seascape videos, considering functional  
621 ecosystem compartments structuring the seascape. The compartments assessed described structuring  
622 communities (filter and suspension feeders, rhodoliths) which contribute to the seascape. For example,  
623 Gobert et al. (2014) proposed the LIMA index, which is based on a topographical and a biological  
624 description and could be applied on all type of habitat from 0 to 40 m depth. Such approach could be  
625 of interest for CDB hosting structuring facies and associations; in the case of CDB without such  
626 features, a low structured seascape cannot be interpreted as a low-functioning ecosystem, considering  
627 the macrofauna of the sediment, compartment of importance but with little consequence on the  
628 seascape structure (bioturbation, calcified organisms providing bioclastic elements, etc.).

629 Our analysis showed strong and expected correlations between some of the descriptors. Defining an  
630 indicator implies the selection of suitable descriptors but not too numerous for an operational  
631 implementation. Our purpose was to assess the main compartments of the ecosystem, as defined in Fig.  
632 1, using as few descriptors as possible. The correlation observed between the final set of descriptors  
633 could lead us to reduce the number of descriptors and then simplify the assessment and avoid  
634 redundancy; at the same time, a combination of correlated descriptors assessing different ecological  
635 functions improves the robustness. As evoked by Personnic et al. (2014), the removal of correlated  
636 boxes might result in a loss of accuracy of the method.

637 An ecosystem-based approach can be useful for Ecosystem Services assessment, providing quantitative  
638 data for the different ecosystem compartments (Seitz et al., 2014; Burgos et al., 2017). Such approach  
639 has already been carried out for several ecosystems, including seagrass meadows and considering  
640 different bundles of ecosystem services according to different quality status (Kermagoret et al., 2019;  
641 Scémama et al., 2020).

### 642 **4.3 A tool to support anthropogenic pressures assessment**

643 The next step should be the design of an anthropogenic pressure assessment tool to estimate the links  
644 between ecological status and anthropogenic cumulated pressures (Holon et al., 2015; Guarnieri et al.,  
645 2016; Quemmerais-Amice et al., 2020). Assessing anthropogenic pressures is challenging; the  
646 moreover, the assessment of human activities can be considered as a good proxy. In the present work,  
647 we did not identify visible evidences of trawling or dredging, the main physical pressures affecting  
648 CDB. These evidences can be difficult to find, even in long-time trawled areas (Ordines et al., 2017).  
649 The main evidences of stress observed were the occurrence of macrowastes (e.g., glass, plastic, fishing  
650 gears) and invasive alien species (e.g., *Caulerpa cylindracea*). A complementary approach is needed  
651 to better characterize human pressures. Our study sites are not located in areas with an important  
652 trawling activity, compared to e.g., the Gulf of Lion, the Catalan Coast or Balearic Islands (Farriols et  
653 al., 2017; Jac and Vaz, 2020). New data in different configurations regarding anthropogenic pressures  
654 are to be sampled.

### 655 **4.4 The need for an effective protection**

656 The increase in the surface area of Marine Protected Areas driven by the European Union since the  
657 2010s has led the MPAs to extend over the continental shelf, including coastal detrital bottoms. The  
658 new borders of these MPAs do not mean automatically an effective protection and management, and  
659 it needs time for coastal managers to include these new areas in dashboards and management plans. As  
660 a results, the ecological status of CDB sites shows no correlation with the management level to the  
661 contrary of Thibaut et al. (2017), who evidenced differences in sublittoral rocky reefs according to the  
662 management, and no statistical difference between Natura 2000 and unprotected sites. These results

663 highlight the need to enhance the conservation of continental shelf widespread ecosystems such as the  
664 CDB, involving the implementation of effective marine protected areas (Sala et al., 2021).

665 The conservation or the restoration of CDB implies the decreasing or at least the regulation of  
666 anthropogenic pressures to allow a natural resilience of communities identified as impacted by such  
667 activities. In that case, the role of effective MPAs is limited to the regulation or prohibition of some  
668 human activities: e.g., trawling, dredging, artisanal fishing, mooring. The regulation of other pressures  
669 (e.g., terrigenous inputs, NIS spreading, eutrophication, sedimentation) asks for larger scale policies.

### 670 **4.5 EBQI implementation for CDB**

671 As an indicator embracing the concept of the ecosystem-based approach, the EBQI defined for CDB  
672 aims to provide relevant and useful data for both European Directives (MSFD, WFD, HD) and local  
673 management purposes. Compared to other indicators dedicated to soft bottoms (e.g., Borja et al., 2000,  
674 2003), the EBQI does not need a strong expertise in taxonomy even if it implies more parameters for  
675 its calculation. Fifteen descriptors are needed to assess the EBQI for CDB, 13 for *Posidonia oceanica*  
676 seagrass meadows (Personnic et al., 2014) and 10 for infralittoral rocky reefs (Thibaut et al., 2017).  
677 Data sampling can be carried out in less than one day per site, involving three operators, which is  
678 reasonable to envisage the settlement of a long-term monitoring network at regional (e.g., French  
679 Mediterranean coast) or local scale (e.g., MPA; Astruch et al., 2022b). The frame proposed by the  
680 EBQI can provide a standardized method to assess the conservation status according to the Habitats  
681 Directive (e.g., assessment of the structure and the function of a given habitat), where diagnosis were  
682 usually based on expert judgement and broad data. Repeated applications over time would be welcome  
683 to evaluate the adequacy of this index to describe change following management actions (Mancini et  
684 al., 2020; Oprandi et al., 2022).

685 EBQI on CDB should be applied and tested in contexts with other biogeographic specificities and  
686 pressures: oligotrophic, warmer and impacted by non-indigenous species where very few knowledge  
687 is available (e.g., South and Eastern Mediterranean Sea). The same approach could also be applied on  
688 subtidal rhodolith beds in other areas worldwide of important concern about related human activities  
689 (e.g., Brittany).

## 690 **5 Conclusion**

691 An original Ecosystem-Based Quality Index (EBQI) for the Coastal Detrital Bottoms (CDB) has been  
692 defined, inspired by already existing EBQIs for *Posidonia oceanica* seagrass meadows, coralligenous  
693 reefs, underwater marine caves, and infralittoral rocky reefs, all mainly based on the assessment of  
694 their epibenthic assemblages. Relatively easy to implement and robust, CDB EBQI provides a relevant  
695 tool to assess the quality of this widespread ecosystem in accordance with public policies at national  
696 and European levels. In the context of the increase in surface areas of marine protected areas,  
697 management goals must include CDB in upcoming plans to secure the conservation of a habitat of  
698 importance at the Mediterranean scale. Our approach is mainly focused on epibenthic assemblages and  
699 improvement should be needed to better consider the assessment of the macrofauna of the sediment.  
700 We suggest applying and testing this approach in other areas within the Mediterranean Sea and outside.

## 701 **6 Conflict of Interest**

702 The authors declare that the research was conducted in the absence of any commercial or financial  
703 relationships that could be construed as a potential conflict of interest.

704 **7 Author Contributions**

705 All authors (excepting AO, NM, BM and BD) have participated in a workshop in Marseille in April  
 706 2019. PA, BB, TS and AO realised the field investigations and the data sampling in 2020 and 2021.  
 707 All authors contributed to the content for their associated sections. TS and AO produced the statistical  
 708 analysis. PA compiled content from all authors and prepared the final version. All authors have  
 709 reviewed and agreed to the submission of the final version.

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1243 Table 1. Sampling sites position (DD: decimal degrees), depth at upper and deep zones (m) and  
 1244 management level (MPA: Marine Protected area; NTZ: No-take zone; MUM: Multi-use management).

Code	Sites	Upper zone			Deep zone			Management level
		Latitude DD	Longitude DD	Z (m)	Latitude DD	Longitude DD	Z (m)	
01COU	La Couronne	43.318006	5.068738	36	43.309006	5.069218	54	Natura 2000
02CAR	Carry	43.322321	5.181404	37	43.31703	5.185064	51	Natura 2000
03PRA	Baie du Prado	43.249276	5.341165	32	43.238208	5.311782	51	MPA-MUM
04PLA	Planier	43.189937	5.224995	33	43.187317	5.226625	58	MPA-NTZ
05PR	Passe de Riou	43.183998	5.367319	42	43.185715	5.355298	59	MPA-NTZ
06SUG	Sugiton	43.207808	5.461533	40	43.20354	5.461815	62	MPA-MUM
07CC	Cap Canaille	43.188278	5.550706	39	43.186743	5.547737	62	MPA-NTZ
08IVE	Île Verte	43.158016	5.614341	49	43.154661	5.608425	68	MPA-MUM
09EMB	Embiez	43.077151	5.740709	38	43.076248	5.733459	63	Natura 2000
10AMP	Amphitria	43.043668	5.84977	39	43.041536	5.850354	61	Natura 2000
11DF	Deux Frères	43.052152	5.869729	41	43.051563	5.875795	62	Natura 2000
12TGR	Toulon Grande Rade	43.094181	6.001158	37	43.075055	5.995539	64	No protection
13FG	Fourmigue de Giens	43.042368	6.067969	42	43.035908	6.068579	64	MPA-MUM
14POR	Porquerolles Est	43.013374	6.257428	38	43.03322	6.297224	49	MPA-MUM
15HB	Baie d'Hyères	43.064543	6.273882	40	43.054147	6.360791	63	MPA-MUM
16BAG	Passe de Bagaud	43.015193	6.376252	41	43.022061	6.383424	63	MPA-MUM
17VAI	Vaisseau	42.993327	6.404658	41	42.9905	6.404757	65	MPA-NTZ
18CAV	Cavalaire	43.173947	6.555193	39	43.16926	6.560022	58	Natura 2000
19CT	Cap Taillat	43.166685	6.659678	43	43.152653	6.669391	79	Natura 2000
20CAM	Cap Camarat	43.193892	6.712775	41	43.188749	6.718136	68	Natura 2000
21PAM	Pampelonne	43.255746	6.758933	42	43.255049	6.766981	66	No protection
22ST	Saint Tropez	43.288836	6.642193	35	43.292658	6.664679	51	No protection
23SAR	Sardinaux	43.31683	6.697555	44	43.318675	6.707096	60	No protection
24DRA	Dramont	43.408298	6.842286	43	43.406108	6.836703	60	Natura 2000
25AGA	Agay	43.41966	6.86717	41	43.417686	6.871251	61	Natura 2000
26EST	Esterel	43.4493	6.92991	39	43.449293	6.934245	61	MPA-NTZ
27TH	Théoule sur mer	43.50549	6.957715	28	43.506943	6.960811	50	MPA-MUM
28ANT	Cap Antibes	43.541966	7.127123	36	43.537103	7.126363	59	Natura 2000
29VIL	Villefranche sur mer	43.691278	7.319585	41	43.692724	7.314388	58	Natura 2000

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1247 Table 2. Boxes, descriptors, weight (W) and status for the EBQI assessment (POM: Particulate Organic  
 1248 Matter; HOM: High Organic Matter; LOM: Low Organic Matter).

			Status					
Box	Descriptors	W	4	3	2	1	0	
1	Rhodoliths	% cover (upper zone)	6	$\geq 20\%$	$20 > x \geq 10\%$	$10 > x \geq 5\%$	$5 > x > 0\%$	0%
		% cover (deep zone)		$\geq 10\%$	$10 > x \geq 5\%$	$5 > x \geq 1\%$	$1 > x > 0\%$	0%
2	Perennial macroalgae	% cover (upper zone)	4	$\geq 2\%$	$2 > x \geq 1\%$	$1 > x \geq 0.2\%$	$0.2 > x \geq 0\%$	0%
3-4	Seasonal erected macroalgae	% cover (upper zone)	4	$\geq 10\%$	$10 > x \geq 5\%$	$5 > x \geq 1\%$	$1 > x > 0\%$	0%
		% cover (deep zone)		$\geq 5\%$	$5 > x \geq 2\%$	$2 > x \geq 1\%$	$1 > x > 0\%$	0%
5	Herbivores	Alpha taxonomic richness	2	$\geq 2$		1		0
6	Sedimented POM	% pelitic (< 63 $\mu\text{m}$ ) in the sediment	2	$< 0.02\%$	$0.05 > x \geq 0.02\%$	$0.1 > x \geq 0.05\%$	$1 > x \geq 0.1\%$	$\geq 1\%$
7	Infauna	% Organic Matter in the sediment (status +2 if matte or remains of <i>Posidonia oceanica</i> in the sample)	5	$3 > x \geq 2\%$	$4 > x \geq 3\%$	$5 > x \geq 4\%$	$2 > x \geq 0\%$	$\geq 5\%$
8	Organic macrodetritus	% cover by litter	2	$10 > x \geq 5\%$	$5 > x \geq 1\%$	$< 1\%$	$25 > x \geq 10\%$	$\geq 25\%$
9a	Detritivores HOM	Mean density per m <sup>2</sup>	3	0	$0.6 > x > 0$	$1 > x \geq 0.6$	$2 > x \geq 1$	$\geq 2$
9b	Detritivores LOM	Mean density per m <sup>2</sup>		$\geq 2$	$2 > x \geq 1$	$1 > x \geq 0.6$	$0.6 > x > 0$	0
10	Filter- and Suspension-feeders	Mean density per m <sup>2</sup>	4	$\geq 30$	$30 > x \geq 15$	$15 > x \geq 10$	$10 > x \geq 5$	$< 5$
11	Planktivores	Alpha specific richness	1	$\geq 2$	-	1	-	0
12a	Carnivorous invertebrates	Alpha taxonomic richness	3	$\geq 5$	4	3	2	$\leq 1$
12b	Carnivorous vertebrates	Alpha taxonomic richness		$\geq 5$	4	3	2	$\leq 1$

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1251 Table 3. Method for the assessment of the descriptors for each functional compartment.

Box	Descriptors	Method	
1	Rhodoliths	% cover (upper zone)	Photoquadrats (80 cm × 80 cm) at upper zone
		% cover (deep zone)	Photoquadrats (80 cm × 80 cm) at intermediate zone
2	Perennial macroalgae	% cover (upper zone)	Photoquadrats (80 cm × 80 cm) at upper zone
3-4	Seasonal macroalgae	% cover (upper zone)	Photoquadrats (80 cm × 80 cm) at upper zone
		% cover (deep zone)	Photoquadrats (80 cm × 80 cm) at intermediate zone
5	Herbivores	Alpha taxonomic richness	SCUBA, photoquadrats and seascape videos
6	Sedimented POM	% pelitic (< 63 µm) in the sediment	3 sediment cores sampled per site. Grain size analysis (< 63 µm)
7	Infauna	% OM in the sediment (status +2 if matte or <i>Posidonia oceanica</i> remains in the sample)	3 sediment cores sampled per site. After drying the samples 48h at 60°C, burn it 4h at 400°C. The difference between the dry weight and the remains after burning is the dry mass of OM.
8	Organic macrodetritus	% cover by litter	Photoquadrats (80 cm × 80 cm) at the 2 depths
9a	Detritivores HOM	Mean density per m <sup>2</sup>	Photoquadrats (80 cm × 80 cm) at the 2 depths
9b	Detritivores LOM	Mean density per m <sup>2</sup>	Photoquadrats (80 cm × 80 cm) at the 2 depths
10	Filter- and Suspension-feeders	Mean density per m <sup>2</sup>	Photoquadrats (80 cm × 80 cm) at the 2 depths
11	Planktivores	Alpha specific richness	SCUBA, photoquadrats and seascape videos
12a	Carnivorous invertebrates	Alpha taxonomic richness	SCUBA, photoquadrats and seascape videos
12b	Carnivorous vertebrates	Alpha taxonomic richness	SCUBA, photoquadrats and seascape videos

1252

1253 Table 4. Ecological status according to EBQI notation.

Colour code	Ecological status	EBQI notation
	Very good	EBQI ≥ 7.5
	Good	7.5 > EBQI ≥ 6
	Intermediate	6 > EBQI ≥ 4.5
	Poor	4.5 > EBQI ≥ 3.5
	Bad	EBQI < 3.5

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1256 Table 5. Confidence index (CI) related with data quality or expert judgement (Criteria from Personnic  
1257 et al., 2014).

<b>CI</b>	<b>Criteria</b>
4	Field data available, recent, and suitable with the recommended methods
3	Field data recent, partially completed with expert judgement
2	No quantitative field data but recent expert judgement
1	No quantitative field data but ancient expert judgement
0	No quantitative field data and no suitable expert judgement

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## Ecosystem-based assessment of Coastal Detrital Bottoms

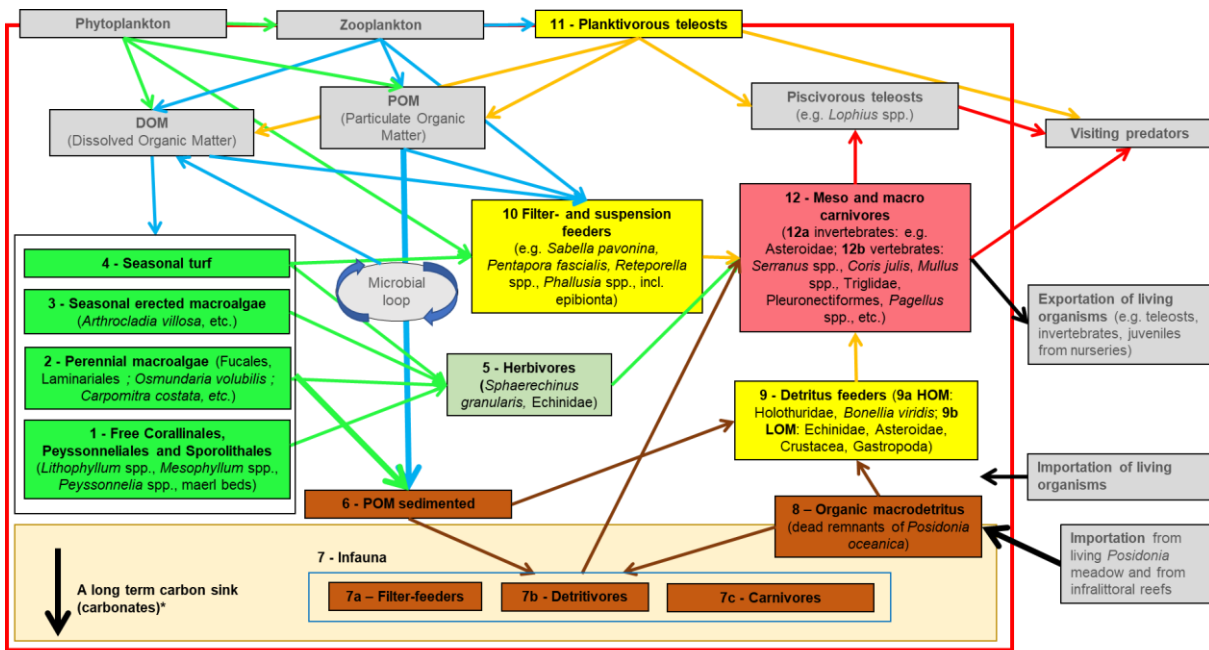
1260 Table 6. EBQI notation, status per box and Circularity value (Cir.) for the 29 sampling sites (see Fig.  
 1261 2 for location). Red: Poor; Yellow: Bad; Green: Intermediate; Blue: Good; Dark Blue: Very Good. UZ:  
 1262 Upper zone; DZ: Deep zone.

Code	Sites	1- UZ	1- DZ	2	3-4- UZ	3-4- DZ	5	6	7	8	9a	9b	10	11	12a	12b	EBQI	Cir.
01COU	La Couronne	0	0	0	1	0	0	1	4	2	4	3	0	0	0	2	<b>2.88</b>	0.44
02CAR	Carry	1	0	1	1	0	4	2	4	3	3	0	1	4	0	4	<b>4.55</b>	0.27
03PRA	Baie du Prado	1	1	1	2	1	2	1	2	3	4	1	2	0	2	4	<b>4.34</b>	0.46
04PLA	Planier	1	2	1	3	2	0	3	4	4	4	2	2	2	2	4	<b>5.9</b>	0.56
05PR	Passe de Riou	2	1	1	2	1	0	1	2	2	3	0	1	0	3	3	<b>3.65</b>	0.45
06SUG	Sugiton	1	1	1	1	1	0	1	1	4	1	0	3	2	1	1	<b>3.30</b>	0.42
07CC	Cap Canaille	1	1	0	1	1	4	3	4	3	1	0	0	2	1	1	<b>3.92</b>	0.58
08IVE	Île Verte	3	1	2	4	2	2	4	4	1	1	3	4	0	3	4	<b>6.84</b>	0.46
09EMB	Embiez	4	2	2	3	2	4	4	3	2	2	3	4	0	1	3	<b>6.98</b>	0.63
10AMP	Amphitria	0	1	0	1	1	0	2	4	3	3	1	0	0	1	0	<b>3.09</b>	0.58
11DF	Deux Frères	1	0	0	1	0	2	1	4	3	3	1	1	0	2	0	<b>3.47</b>	0.48
12TGR	Toulon Grande Rade	1	1	0	2	3	2	1	4	3	1	0	4	0	1	0	<b>4.65</b>	0.29
13FG	Fourmigue de Giens	1	2	2	3	1	0	3	4	3	1	1	3	0	3	2	<b>5.52</b>	0.41
14POR	Porquerolles Est	3	4	4	2	4	2	1	4	2	1	3	1	0	3	2	<b>6.70</b>	0.48
15HB	Baie d'Hyères	4	2	2	4	4	4	2	0	2	4	3	1	0	4	3	<b>5.76</b>	0.48
16BAG	Passe de Bagaud	4	4	4	4	4	4	1	3	2	1	2	1	2	4	1	<b>7.15</b>	0.52
17VAI	Vaisseau	4	2	4	4	4	0	3	4	3	3	1	4	0	0	3	<b>7.53</b>	0.39
18CAV	Cavalaire	1	3	1	2	2	4	1	4	3	0	1	3	0	4	1	<b>5.63</b>	0.27
19CT	Cap Taillat	4	2	1	2	1	4	1	0	2	2	3	4	2	4	1	<b>5.21</b>	0.41
20CAM	Cap Camarat	4	3	1	3	2	4	1	4	2	3	4	1	0	1	1	<b>6.01</b>	0.40
21PAM	Pampelonne	4	4	2	4	4	4	4	4	2	4	3	2	2	2	3	<b>8.06</b>	0.73
22ST	Saint Tropez	0	0	0	1	0	0	1	4	3	1	0	0	2	2	2	<b>2.74</b>	0.51
23SAR	Sardinaux	4	0	1	4	1	2	1	3	2	0	0	3	4	0	4	<b>5.07</b>	0.33
24DRA	Dramont	4	1	2	3	1	2	1	1	3	0	3	4	4	2	4	<b>5.66</b>	0.54
25AGA	Agay	1	1	1	2	1	0	1	4	1	1	3	0	0	4	4	<b>4.03</b>	0.33
26EST	Esterel	3	4	2	2	2	4	1	3	2	3	4	2	0	2	4	<b>6.49</b>	0.49
27TH	Théoule sur mer	1	0	0	2	1	2	0	0	3	3	1	0	0	1	2	<b>2.05</b>	0.43
28ANT	Cap Antibes	1	2	1	2	1	4	0	2	0	3	1	3	0	4	4	<b>4.65</b>	0.25
29VIL	Villefranche sur mer	1	0	1	2	1	2	1	4	4	1	2	2	2	3	4	<b>5.00</b>	0.54

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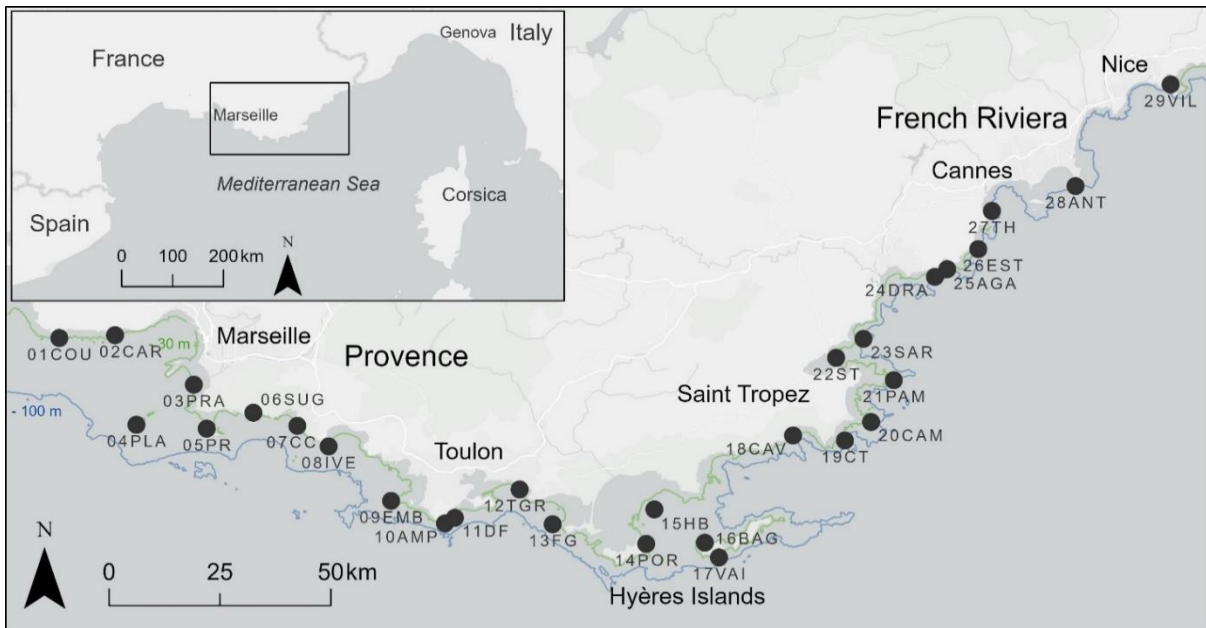
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## Ecosystem-based assessment of Coastal Detrital Bottoms



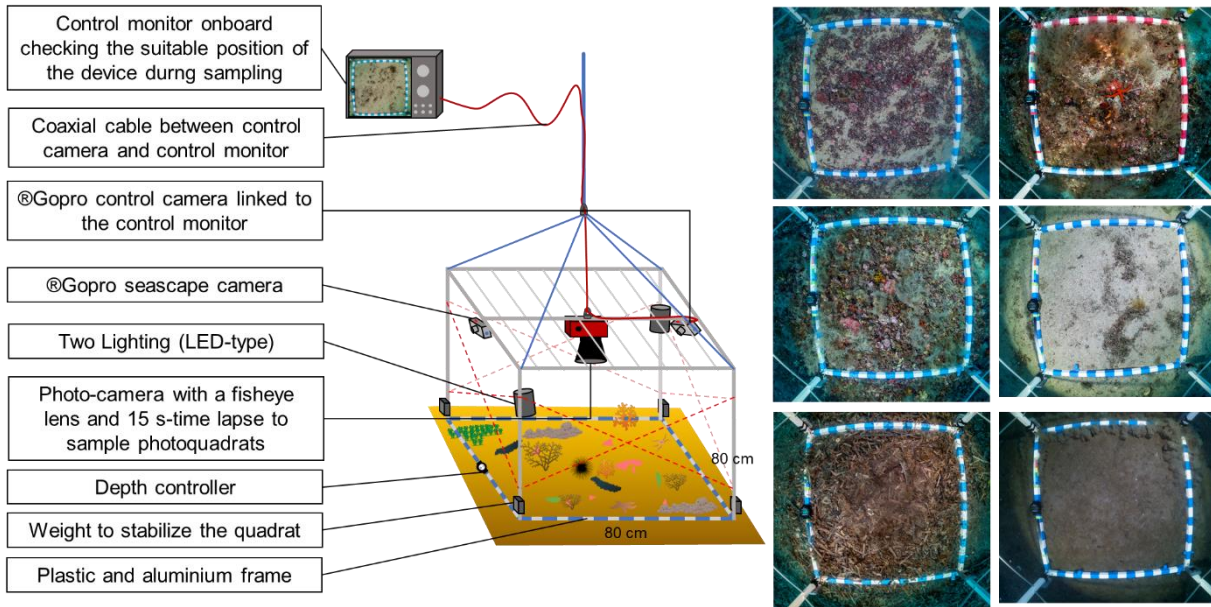
1265

1266 Figure 1. Conceptual functional model of the Coastal Detrital Bottom Ecosystem. Arrows correspond  
 1267 to a flux of organic matter between boxes. Light grey boxes are not assessed directly. \*See  
 1268 corresponding paragraph for more details about Carbon sink.



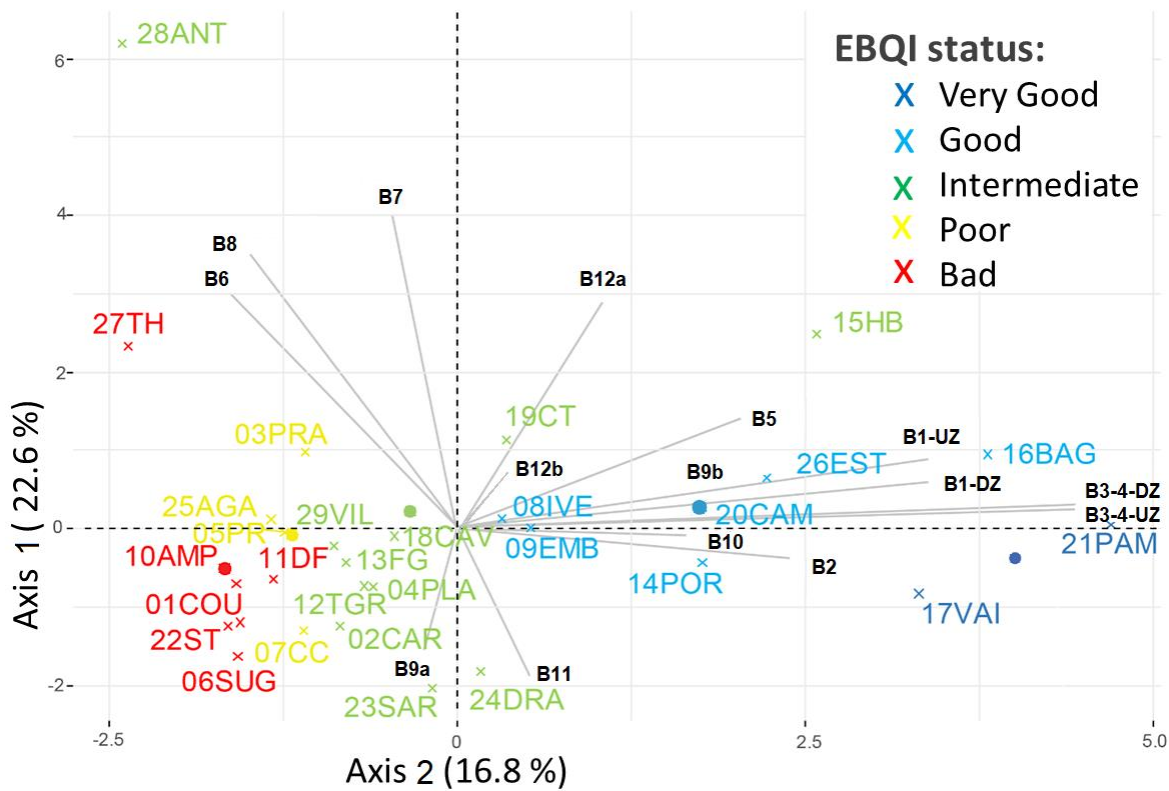
1269

1270 Figure 2. Study area along the French Mediterranean coast and location of the 29 sampling sites.



1271

1272 Figure 3. Diagram of the Biocube device. The pictures on the right show different types of CDB  
 1273 sampled on photoquadrats.

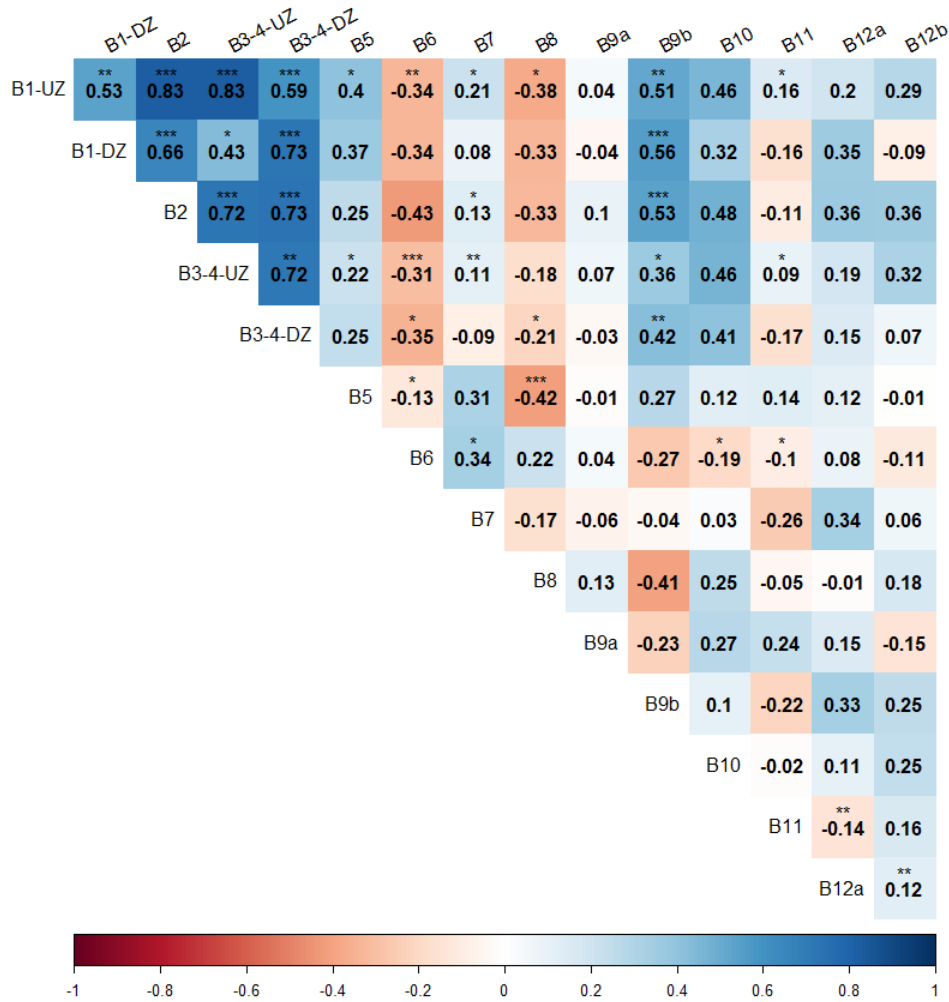


1274

1275 Figure 4. Principal Component Analysis. Sampling sites are coloured according to their EBQI notation.  
 1276 Boxes descriptors are projected in light grey. Red: Poor; Yellow: Bad; Green: Intermediate; Blue:  
 1277 Good; Dark Blue: Very Good.

1278

## Ecosystem-based assessment of Coastal Detrital Bottoms



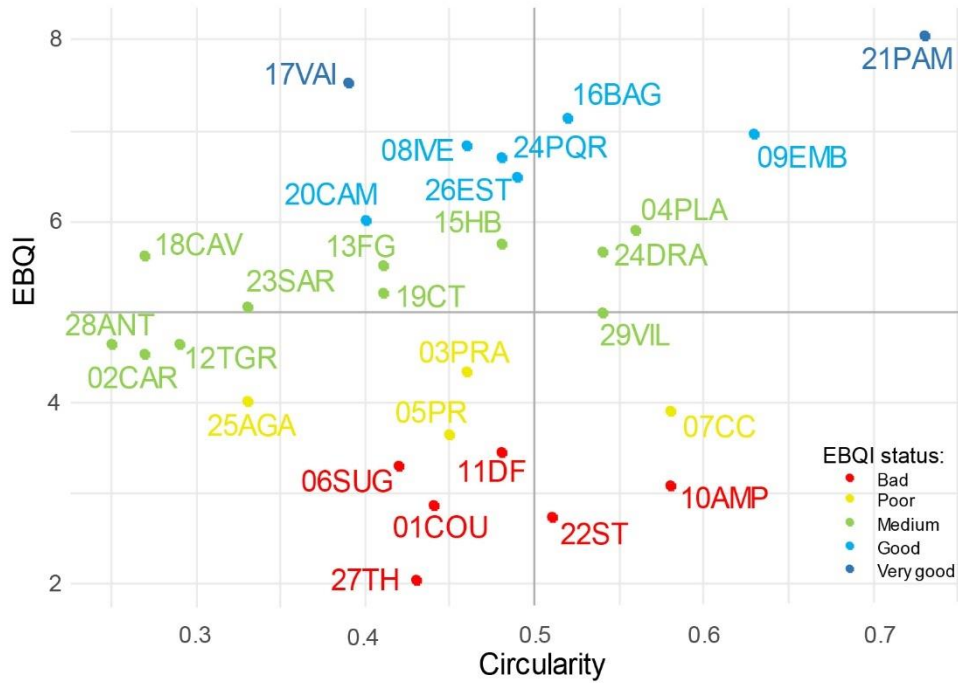
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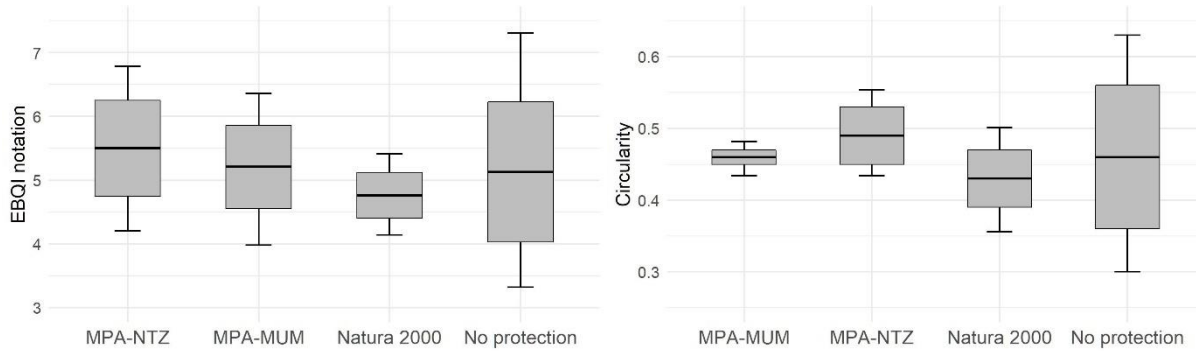
1282

Figure 5. Spearman rank correlation between the fifteen descriptors related to ecosystem boxes of the coastal detrital bottoms. The number in bold is the correlation coefficient R. \*: p < 0.05; \*\*: p < 0.01; \*\*\*: p < 0.001. Blue: positive correlation; Red: Negative correlation.



1283

1284 Figure 6. Scores of EBQI and Circularity for the 29 sites. Red: Poor; Yellow: Bad; Green: Intermediate;  
 1285 Blue: Good; Dark Blue: Very Good.

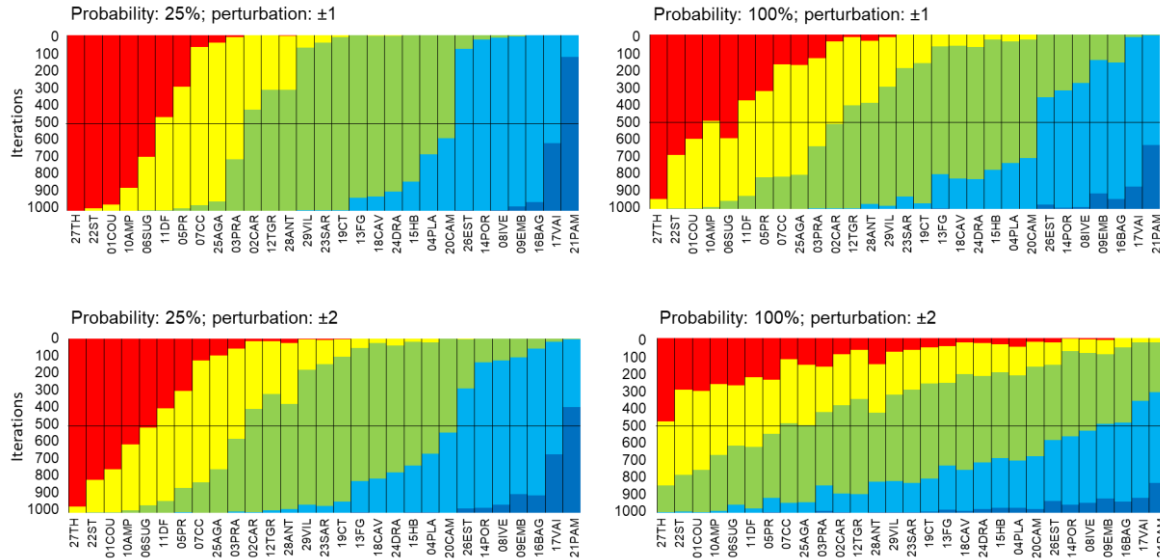


1286

1287 Figure 7. Box plots showing EBQI notation (left) and circularity value (right) according management  
 1288 level. The black crossbar corresponds to the mean EBQI notation, the grey rectangle corresponds to  
 1289 the standard error, the vertical bars correspond to the 95% confidence interval.

1290

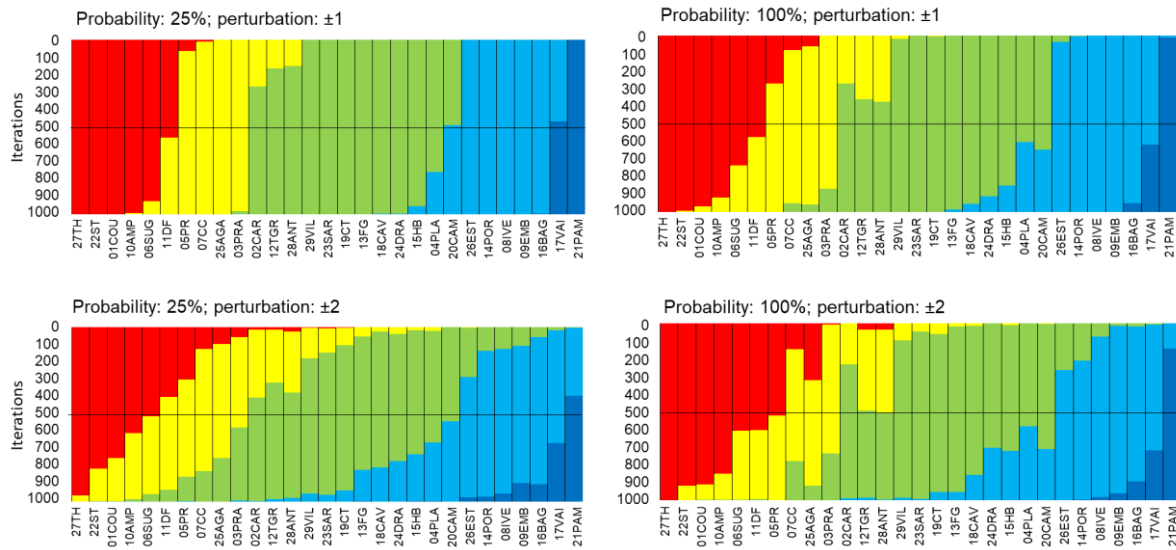
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1293

1294 Figure 8. Robustness of the EBQI with regard to the Ecological status per box. Sampling sites are  
 1295 sorted in ascending order according to the EBQI notation from left to right. In order to test the effect  
 1296 of the status per box on the EBQI (robustness), status values have been randomly perturbed (above,  
 1297  $\pm 1$ ; below,  $\pm 2$ ) 25% (left) and 100% (right) of probability; 1000 iterations were performed. The change  
 1298 of the EBQI notation (bad through very good) of a site, for a given iteration, is shown by the colour of  
 1299 the new class in which it falls). Red: Poor; Yellow: Bad; Green: Intermediate; Blue: Good; Dark Blue:  
 1300 Very Good.



1301

1302

1303 Figure 9. Robustness of the EBQI with regard to the weighting per box. Sampling sites are  
 1304 sorted in ascending order according to the EBQI notation from left to right. In order to test the effect of the  
 1305 weighting per box on the EBQI (robustness), status values have been randomly perturbed (above,  $\pm 1$ ;  
 1306 below,  $\pm 2$ ) 25% (left) and 100% (right) of probability; 1000 iterations were performed. The change of  
 1307 the EBQI notation (bad through very good) of a site, for a given iteration, is shown by the colour of  
 1308 the new class within which it falls). Red: Poor; Yellow: Bad; Green: Intermediate; Blue: Good; Dark  
 1309 Blue: Very Good.