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1 **The CARLIT method for the assessment of the ecological quality of European**
2 **Mediterranean waters: relevance, robustness and possible improvements**

3

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16

17 **Abstract**

18 The application of the European Union (EU) Water Framework Directive (WFD) requires the
19 assessment of the ecological status (ES) of coastal waters in order to detect environmental
20 changes and implement management plans to prevent their further deterioration. The ES of a
21 water body (WB) has to be assessed on the basis of the status of several biological indicators,
22 referred to as biological quality elements (BQE), such as phytoplankton, macroalgae,
23 seagrasses, macroinvertebrates and fish. We present the most extensive assessment ever
24 undertaken of the ES of Mediterranean waters, by means of the CARLIT index, the most widely
25 used index for the Mediterranean Sea. This index is based on the Ecological Quality Ratio
26 (EQR) between a measured value of Ecological Quality (EQ) and a value corresponding to a
27 reference site. This assessment is based on an extensive field study, covering the whole of the
28 Mediterranean French coasts (including Corsica), 40 WBs and ~2 970 kilometres of shore (at a
29 1/2 500 scale). The original Ballesteros CARLIT method is compared to the Nikolić modified
30 method, and we have undertaken the challenge of developing an alternative new simplified
31 CARLIT method. This simplified method, which requires less expert judgement, is easier to
32 implement by local authorities, and provides results similar overall to those of the original
33 method. Previous attempts, if any, to correlate EQRs with anthropogenic stressors (through

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34 pressure indices) were mainly based upon land uses or on comprehensive lists of stressors, some
35 spatially very sporadic, temporally highly variable, non-representative of the WB and with the
36 impact poorly established on species and communities. To date, the LUSI (Land Uses
37 Simplified Index) and the MA-LUSI-WB have been the most widely used pressure indices.
38 Here, we propose a new pressure index (HAPI) taking into consideration the possible
39 shortcomings of previous indices. It takes into account the actual pressures at community levels
40 considered by the CARLIT method. It accounts well for the EQR values of the study area, as
41 evidenced by the high correlation coefficient between EQRs and HAPI, better than that of the
42 other pressure indices. The present study provides a comprehensive view of the ES of the
43 French Mediterranean coasts. Surprisingly, the picture is far less cause for concern than
44 expected, although this could result from an artefact due to the focus on superficial waters and
45 habitats inherent to the CARLIT method. Where two successive assessments were performed
46 (23 WBs, 2007-2010 vs 2012-2015), the results were similar, which stresses the robustness of
47 the method and/or the relative stability over time of the overall ES of the WBs, and suggests
48 that the successive assessments could be carried out at low frequency.

49

50

51 **Keywords:** Biological indicator; Macrophytes; Mediterranean Sea; Pressure index; Ecological
52 Status, HAPI index

53

54 **1. Introduction**

55 The coastal shore is an area that is strongly influenced by anthropogenic pressures, e.g. the
56 constant growth of the population and its socio-economic activities, including agriculture,
57 fisheries and aquaculture, industry and tourism. Coastal marine ecosystems are heavily affected
58 throughout the world. The impact on the environment is multiple and cumulative, including
59 habitat destruction, overfishing, pollution, species introduction, sea-level rise and global
60 warming. None of these pressures is isolated and their cumulative effects impact the coastal
61 marine ecosystems and their ability to deliver ecological goods and ecosystem services (Worm
62 et al., 2006; Halpern et al., 2008; Waycott et al., 2009).

63 Monitoring networks have been set up in order to better understand the putative impact of
64 anthropogenic pressures on various biotopes (Mann, 2000). The European Union (EU) has
65 introduced legislative measures to mitigate the impact on ecosystems of anthropogenic

66 pressures. Since the early 1990s, the EU has adopted framework legislation to regulate the
67 sustainable use of the environment, while protecting, and where necessary restoring, the good
68 quality of the environment. In the framework legislation Birds and Habitats Directives (Council
69 Directive 79/409/EEC, amended by Council Directive 2009/147/EC and Council Directive
70 92/43/EEC), the EU established a list of rare and threatened species, and rare natural habitat
71 types, which are protected in their own right (Member States), to designate a network of
72 protected sites ('Natura 2000 sites'). While these Directives also took into account the marine
73 realm, more recently the EU Marine Strategy Framework Directive, MSFD, (Council Directive
74 2008/56/EC) established a specific framework for conservation in the field of marine
75 environmental policy. The application of the European Water Framework Directive, WFD
76 (Council Directive 2000/60/EC) requires the assessment of the ecological status of coastal
77 waters in order to detect environmental changes and implement management plans to prevent
78 their further deterioration. This EU Directive recommends working on the basis of water bodies
79 (WB). France has 11 523 surface WBs (rivers, lakes, transitional waters, and coastal waters)
80 and 574 groundwater WBs. Of the 180 coastal WBs on French coastlines, only 47 are situated
81 along the French Mediterranean coast: 33 between the Spanish border and the Italian border
82 and 14 in Corsica (Ifremer, 2015). The ecological status of a WB has to be assessed on the basis
83 of the status of several biological indicators referred to as Biological Quality Elements (BQE),
84 such as phytoplankton, macroalgae, seagrasses, macroinvertebrates and fishes, and hydro-
85 morphological and physico-chemical quality elements.

86 To assess the ecological status of coastal water bodies in the WFD, a wide range of biological
87 indices using macrophytes as BQE has been developed along the Mediterranean coasts, such as
88 CARLIT (CARTography LITtoral), CCO (Cover Characteristic species Opportunistic species),
89 CFR (Calidad de Fondos Rocosos), EEI (Ecological Evaluation Index), E-MaQI (Expert-
90 Macrophyte Quality Index), ICS (Index of Community Structure), MarMAT (Marine
91 Macroalgae Assessment Tool), RICQI (Rocky Intertidal Community Quality Index), and RSL
92 (Reduced Species List) (Panayotidis et al., 1999, 2004; Orfanidis et al., 2001, 2003, 2011;
93 Simboura et al., 2005; Ballesteros et al., 2007; Buia et al., 2007; Mangialajo et al., 2007; Wells
94 et al., 2007; Guinda et al., 2008, 2014a, 2014b; Juanes et al., 2008; Orlando-Bonaca et al., 2008;
95 Asnaghi et al., 2009; Azzopardi and Schembri, 2009; Iveša et al., 2009; Sfriso et al., 2009;
96 Sfriso and Facca, 2011; Bermejo et al., 2012, 2013a, 2013b; Díez et al., 2012; Neto et al., 2012;
97 Nikolić et al., 2013; Ar Gall and Le Duff, 2014; Ferrigno et al., 2014; Ar Gall et al., 2016;

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98 Blanfuné et al., 2016). Most of them are based on sampling along transects or at a few stations
99 along the coast (Mangialajo et al., 2007; Juanes et al., 2008; Asnaghi et al., 2009; Iveša et al.,
100 2009; Bermejo et al., 2012; Neto et al., 2012; Nikolić et al., 2013; Guinda et al., 2014a, 2014b).
101 The CARLIT index (Ballesteros et al., 2007) is the only one to take into account the entire
102 rocky coastline of a coastal WB. In addition, this index is the most widely used in the EU
103 Mediterranean countries (Spain, France, Italy, Malta and Croatia) and in one non-EU country
104 (Albania) (Ballesteros et al., 2007; Buia et al., 2007; Mangialajo et al., 2007; Omrane et al.,
105 2010; Blanfuné et al., 2011; Sfriso and Facca, 2011; Bermejo et al., 2012, 2013a; Nikolić et al.,
106 2013; Ferrigno et al., 2014; Blanfuné et al., 2016).

107 The CARLIT method is based upon the mapping of mid-littoral and upper infralittoral species
108 and communities of rocky shores that are considered as good descriptors of the environmental
109 water quality. Evidence on the effects of industrial and wastewater discharges have been widely
110 reported for shallow species, highlighting different sensitivity levels for different coastal
111 assemblages (e.g. Bellan-Santini, 1968; Arnoux and Bellan-Santini, 1972; Bellan and Bellan-
112 Santini, 1972; Belsher and Boudouresque, 1976; Belsher, 1977; Chryssovergis and Panayotidis,
113 1995; Soltan et al., 2001; Terlizzi et al., 2002). Long-lived macrophytes such as *Cystoseira* spp.
114 (Fucales, Phaeophyceae) are evidence of long, relatively disturbance-free periods and good
115 water quality, in contrast to some ephemeral or opportunistic species that respond quickly to
116 any environmental disturbances, such as the articulated red algae of the genera *Corallina*
117 Linnaeus and *Ellisolandia* K.R.Hind & G.W.Saunders (Corallinales, Rhodophyta) and the
118 mussel *Mytilus galloprovincialis* Lamarck, 1819 (Mytiloidea, Mollusca), that are indicative of
119 medium water quality, and some species of green algae such as *Ulva* spp., *Cladophora* spp. that
120 usually characterize waters of poor quality (e.g. Fernandez and Niell, 1982; Thomas, 1983;
121 Janssens et al., 1993; Orfanidis et al., 2001; Panayotidis et al., 2004; Arévalo et al., 2007;
122 Ballesteros et al., 2007; Mangialajo et al., 2007; Cecchi et al., 2009; Maggi et al., 2009; Falace
123 et al., 2010; Sfriso and Facca, 2011; Nikolić et al., 2013).

124 The relevance of biological indices has to be validated by putting them in correlation with the
125 anthropogenic pressures acting in the study area, in order to establish the link between the
126 ecological status of the coastal WB and the biological quality elements (BQE) used. All existing
127 indices have been more or less correlated with pressure indices such as the LUSI Index (Land
128 Use Sustainability Index), but the link has been assessed empirically and not clearly established,
129 or not dealt with at all (Orfanidis et al., 2001, 2003, 2011; Mangialajo et al., 2003, 2007;

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130 Panayotidis et al., 2004; Simboura et al., 2005; Ballesteros et al., 2007; Buia et al., 2007; Juanes
131 et al., 2008; Orlando-Bonaca et al., 2008; Azzopardi and Schembri, 2009; Iveša et al., 2009;
132 Omrane et al., 2010; Bermejo et al., 2012, 2013a, 2013b; Diez et al., 2012; Neto et al., 2012;
133 Nikolić et al., 2013; Ferrigno et al., 2014, Guinda et al., 2014a; ArGall et al., 2016). Moreover,
134 parameters used to determine the correlation with biological indices were often not relevant
135 pressures for the species and communities considered. A relevant link requires that the
136 considered pressures would have an actual impact on species or communities of interest, and
137 would be quantifiable at the scale of a WB and for all the water bodies considered.

138 The aims of this study are i) to assess the ecological status of the water bodies of the French
139 Mediterranean coasts by means of the CARLIT method, the first assessment undertaken over
140 such an extensive shoreline (~2 970 kilometres), ii) to calculate the relationship between the
141 CARLIT index and different, already-existing anthropogenic pressure indices, iii) to propose
142 and to test a new index of anthropogenic pressures (HAPI), better correlated with the CARLIT
143 index than previous pressure indices, iv) to discuss changes in the CARLIT index scores
144 between two successive surveys (2007-2010 vs 2012-2015), and v) to discuss possible
145 improvements to the CARLIT index, requiring less expert judgement and making it easier to
146 implement by local authorities.

147

148 **2. Material and methods**

149

150 **2.1. Study area and coastal water bodies**

151

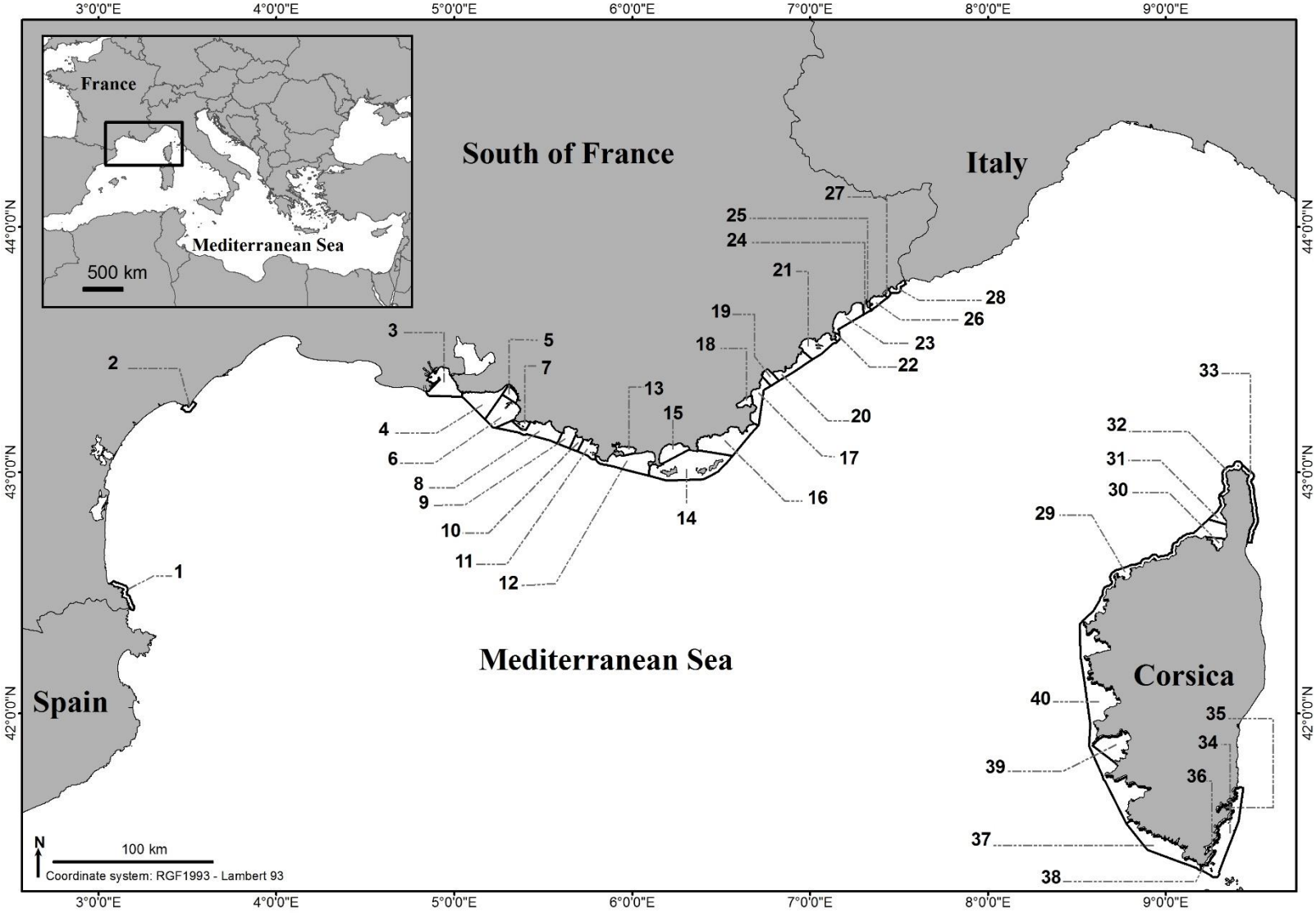
152 The CARLIT method only applies to coastal water bodies dominated by rocky shores where
153 macrophytes can be used as BQE. Of the 47 French coastal water bodies, 40 are concerned by
154 this study; the others, which are mainly fringed by sandy shores, are not considered here (Figure
155 1).

156

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157 A first assessment of the considered water bodies was conducted in 2007 and 2008 on the
158 mainland and in 2009 and 2010 in Corsica. A second assessment was run in 2012 and 2015
159 (Table 1).

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Figure 1. Study area and coastal water bodies assessed. See Table 1 for the meaning of the numbers.

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157 **Table 1.** The 40 coastal water bodies assessed by the CARLIT method and the sampling dates
 158 for each area (nra = not re-assessed). Between square brackets, English translation of the water
 159 body (WB) name and further geographical information, where necessary.

N°	Administrative name of the WB (in French) [English translation]	First assessment	Second assessment
1	FRDC01 - Frontière espagnole - Racou plage [Spanish border - Racou beach]	2007	2012
2	FRDC02c - Cap d'Agde	2007	2012
3	FRDC04 - Golfe de Fos	2007	2012
4	FRDC05 - Côte Bleue [between Couronne and Pointe de Corbières]	2007	2015
5	FRDC06a - Petite Rade de Marseille [between Pointe de Corbières and Pointe d'Endoume, not including Frioul Islands]	2007	2012
6	FRDC06b - Pointe d'Endoume - Cap Croisette et îles du Frioul [between Pointe d'Endoume and Cap Croisette, including Frioul Islands and Planier Island]	2007	2012
7	FRDC07a - Îles de Marseille hors Frioul [Riou Archipelago: Maire, Tiboulens de Maire, Jarre, Jarron, Plane, Petit Congloué, Grand Congloué and Riou Islands]	2007	2015
8	FRDC07b - Cap Croisette - Bec de l'Aigle	2007	2015
9	FRDC07c - Bec de l'Aigle - Pointe Fauconnière	2008	2015
10	FRDC07d - Pointe Fauconnière - Îlot Pierreplane	2008	2015
11	FRDC07e - Îlot Pierreplane - Pointe du Gaou	2007	nra
12	FRDC07f - Pointe du Gaou - Pointe Escampobariou	2008	2015
13	FRDC07g - Cap Cépet - Cap de Carqueiranne	2007	2015
14	FRDC07h - Brégançon - Îles du Soleil [From Escampobariou to Cap de l'Esterel, and from Cap de Brégançon to Cap Bénat, excluding the inner gulf of Giens and including Porquerolles Island, Port-Cros Archipelago and Le Levant Island]	2007	nra
15	FRDC07i - Cap de l'Esterel - Cap de Brégançon	2008	nra
16	FRDC07j - Cap Bénat - Cap Camarat	2008	nra
17	FRDC08a - Cap Camarat - Pointe des Issambres	2008	nra
18	FRDC08b - Golfe de Saint-Tropez	2008	2015
19	FRDC08c - Fréjus - Saint-Raphaël - Ouest de Sainte-Maxime [From west of Sainte-Maxime to Saint-Raphaël]	2008	2012
20	FRDC08d - Ouest Fréjus - Pointe de la Galère	2007	2015
21	FRDC08e - Pointe de la Galère - Cap d'Antibes	2008	nra
22	FRDC09a - Cap d'Antibes - Sud Port d'Antibes [From Cap d'Antibes to the south of Antibes harbour]	2007	nra
23	FRDC09b - Port d'Antibes - Port de commerce de Nice [From Antibes harbour to the commercial port of Nice]	2007	2012
24	FRDC09c - Port de commerce de Nice - Cap Ferrat [From the commercial port of Nice to Cap Ferrat]	2007	nra
25	FRDC09d - Rade de Villefranche [Bay of Villefranche-sur-Mer]	2007	2012

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26	FRDC10a - Cap Ferrat - Cap d'Ail	2007	nra
27	FRDC10b - Cap d'Ail - Monte Carlo [From Cap d'Ail to the eastward border of the Monaco Principality]	2008	2012
28	FRDC10c - Monte Carlo - Frontière italienne [From the eastward border of the Monaco Principality to the Italian border]	2008	nra
29	FREC01ab - Sud Nonza - Punta Palazzu [From south of Nonza to Punta Palazzu]	2010	nra
30	FREC01c - Golfe de Saint-Florent	2009	2012
31	FREC01d - Canari	2009	2015
32	FREC01e - Ouest du Cap Corse [western coast of Cap Corse]	2009	nra
33	FREC02ab - Est du Cap Corse [eastern coast of Cap Corse]	2009	2015
34	FREC03ad - Littoral sud est de la Corse [southeastern coast of Corsica]	2010	nra
35	FREC03b - Golfe de Porto-Vecchio	2009	2012
36	FREC03c - Golfe de Santa Amanza	2009	nra
37	FREC03eg - Littoral sud-ouest [southwestern coast of Corsica]	2009	nra
38	FREC03f - Goulet de Bonifacio [the cove of Bonifacio, mainly occupied by the commercial port and marina]	2009	2012
39	FREC04ac - Golfe d'Ajaccio	2009	nra
40	FREC04b - Punta Senetosa - Punta Palazzu	2010	nra

160

161 2.2. Calculation of the CARLIT index

162

163 The ecological status of coastal water bodies in the study area was assessed by means of the
 164 CARLIT method (Ballesteros et al., 2007). The CARLIT method is based upon the mapping of
 165 geomorphological characteristics obtained in the field (slope, morphology and natural/artificial
 166 substrate) and some mid-littoral and shallow subtidal species and communities of the rocky
 167 shoreline.

168 In the present study, three methods of calculation of the CARLIT Index have been applied to
 169 the same data set and coastal water bodies: the classical method described by Ballesteros et al.
 170 (2007), the Nikolić et al. (2013) method and an alternative simplified method proposed here.

171 In the classical method (hereafter: original CARLIT method), six relevant geomorphological
 172 situations were distinguished according to the coastline morphology and natural/artificial
 173 substrates (Table 2). The species and communities taken into account, according to a decreasing

174 level of sensitivity (from 20, very sensitive, to 1, not sensitive) to disturbance, are listed in Table
175 3.

176 Table 2. Geomorphological situations with their ecological quality values calculated under
177 reference conditions (EQ_{rsi}). ‘Low coast’ means a cliff lower than 15 m; ‘high coast’ means a
178 cliff higher than 15 m (from Ballesteros et al., 2007; Ballesteros pers. comm.).

Geomorphological situation (i)	Coastal morphology	Substrate	EQ_{rsi}
1	Decimetric blocks	Artificial	12.1
2	Low coast	Artificial	11.9
3	High coast	Artificial	8.0
4	Decimetric blocks	Natural	12.2
5	Low coast	Natural	16.6
6	High coast	Natural	15.3

179

180 For each geomorphological situation, the length of the coast occupied by each species or
181 community was measured and the ecological quality value (EQ) was calculated using the
182 formula:

$$183 \quad EQ_{ssi} = \frac{\sum(l_j * SL_j)}{\sum l_j}$$

184 Where i is the geomorphological situation; EQ_{ssi} is the ecological quality value of the
185 geomorphological situation i; l_j is the length of the coastline with the species or community j,
186 SL_j is the sensitivity level of the species or community j (Table 3) and $\sum l_j$ is the total length of
187 the coastline occupied by the geomorphological situation i.

188 According to the WFD, the ecological status of a coastal WB has to be expressed in terms of
189 ecological quality ratios (EQR). This ratio indicates the relationship between the value of the
190 biological parameters (here, species and communities) recorded for a given coastal WB and the
191 value for these parameters under the reference conditions applicable to this water body.

192

193

194

195

196 Table 3. Species and communities taken into account in the CARLIT Index (classical method),
 197 with their ‘sensitivity level’ (SL) according to Ballesteros et al. (2007), with their description
 198 in the study area.

Species and communities	Description in the study area	SL
<i>Cystoseira mediterranea</i> / <i>amentacea</i> 5	Continuous stands of <i>C. mediterranea</i> or <i>C. amentacea</i>	20
<i>Cystoseira crinita</i>	Stands of <i>C. crinita</i>	20
<i>Cystoseira balearica</i>	Stands of <i>C. brachycarpa</i> (a)	20
Other shallow <i>Cystoseira</i> species	Stands of <i>C. foeniculacea</i> , <i>C. barbata</i> , <i>C. spinosa</i> var. <i>tenuior</i> , <i>C. compressa</i> subsp. <i>pustulata</i> (b)	20
<i>Posidonia</i> reefs	Barrier and fringing reefs of <i>Posidonia oceanica</i> (Magnoliophyta)	20
<i>Cymodocea nodosa</i>	<i>Cymodocea nodosa</i> (Magnoliophyta) meadows	20
<i>Zostera noltii</i>	<i>Zostera noltei</i> (Magnoliophyta) meadows (c)	20
<i>Lithophyllum byssoides</i> rims	Bioconstructions of <i>L. byssoides</i> (Rhodophyta)	20
<i>Cystoseira mediterranea</i> / <i>amentacea</i> 4	Almost continuous stands of <i>C. amentacea</i> or <i>C. mediterranea</i>	19
<i>Cystoseira mediterranea</i> / <i>amentacea</i> 3	Abundant patches of dense stands of <i>C. amentacea</i> or <i>C. mediterranea</i>	15
<i>Cystoseira mediterranea</i> / <i>amentacea</i> 2	Abundant scattered plants of <i>C. amentacea</i> or <i>C. mediterranea</i>	12
<i>Cystoseira compressa</i>	Stands of <i>C. compressa</i> subsp. <i>compressa</i>	12
<i>Cystoseira mediterranea</i> / <i>amentacea</i> 1	Rare scattered plants of <i>C. amentacea</i> or <i>C. mediterranea</i>	10
<i>Corallina elongata</i>	Stands of articulated Corallinales without <i>Cystoseira</i> species (d)	8
<i>Haliptilon virgatum</i>	Stands of epiphytic articulated Corallinales without <i>Cystoseira</i> (e)	8
<i>Mytilus galloprovincialis</i>	<i>M. galloprovincialis</i> (mussel) beds without <i>Cystoseira</i>	6
Encrusting corallines	Communities of <i>Lithophyllum incrustans</i> , <i>Neogoniolithon brassica-florida</i> and other encrusting corallines (Rhodophyta)	6
Green algae	Stands of <i>Ulva</i> spp. and/or <i>Cladophora</i> spp. (Chlorobionta)	3
Blue green algae	Communities dominated by Cyanobacteria (f)	1

199 (a) *C. balearica* is a heterotypic synonym of *C. brachycarpa*. (b) *C. spinosa* var. *tenuior* was not
 200 observed during the survey (c) *Zostera noltei* is the correct name for *Z. noltii*. (d) Several species of
 201 articulated Corallinales, not distinguishable in the field, can occur in the Mediterranean Sea, e.g.
 202 *Ellisolandia elongata* (synonym: *C. elongata*), *Corallina caespitosa* and *C. officinalis*. (e) *Haliptilon*
 203 *virgatum* is an epiphytic species not distinguishable in the field, if not collected, from other epiphytic
 204 articulated Corallinales such as *Jania* spp. (f) Ballesteros et al. (2007) added the Chlorobionta *Derbesia*
 205 *tenuissima*; this species is not easy to see and impossible to identify in the field; we therefore did not
 206 consider it.
 207

208 The EQR (Ecological Quality Ratio) of a geomorphological situation of a coast is calculated as
 209 the ratio between the EQs measured (EQ_{ssi}) and the EQ of reference sites corresponding to the
 210 same ‘geomorphological situation’ with species and communities of highest sensitivity level
 211 (EQ_{rsi}) (Table 2). Therefore, the EQR of a coast corresponding to a coastal WB is calculated
 212 according to the following formula:

213
$$EQR = (\sum[(EQ_{ssi}/EQ_{rsi}) * l_i] / \sum l_i)$$

214 Where *i* is the geomorphological situation; EQ_{ssi} is the EQ at the study site for the
 215 geomorphological situation *i*; EQ_{rsi} is the EQ at the reference sites for the geomorphological
 216 situation *i*; l_i is the coastal length occupied by the geomorphological situation *i* ($l_i = \sum l_j$) and $\sum l_i$
 217 is the total length of the coastline of the coastal WB ($\sum l_i = \sum \sum l_j$).

218 The EQR is expressed as a numerical value between 0 and 1. The ecological status of a coastal
 219 WB is defined as follows:

EQR	Ecological status
1 to >0.75	High
0.75 to >0.60	Good
0.60 to >0.40	Moderate
0.40 to >0.25	Poor
0.25 to 0.0	Bad

220

221 Nikolić et al. (2013) developed a slightly modified CARLIT index for the eastern Adriatic Sea
 222 (hereafter: Nikolić method). The equations and the rationale are the same as described by
 223 Ballesteros et al. (2007). The differences lie in the relevant geomorphological situations (Table
 224 4), in some species and communities, and in their sensitivity levels (Table 5).

225

226 Table 4. Geomorphological situations with their ecological quality values calculated under
 227 reference conditions (EQ_{rsi}), from Nikolić et al. (2013). ‘Low coast’ means a cliff lower than
 228 15 m; ‘high coast’ means a cliff higher than 15 m (from Ballesteros et al., 2007; Ballesteros
 229 pers. comm.).

Geomorphological situation (i)	Coastal morphology	Coastline slope	EQ_{rsi}
1	High coast	Horizontal	20.00
2	High coast	Sub-vertical	17.55
3	High coast	Vertical	12.96
4	High coast	Overhanging	10.00
5	Low coast	Horizontal	19.02
6	Low coast	Sub-vertical	17.72
7	Low coast	Vertical	14.62

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8	Low coast	Overhanging	9.66
9	Blocks	-	12.76

230

231 Table 5. Species and communities taken into account for the calculation of the CARLIT Index,
232 and their ‘sensitivity level’ (SL), according to Nikolić et al. (2013), with the description adapted
233 to the study area.

Species and communities	Description in the study area	(SL)
<i>Cystoseira spicata</i> 3	Continuous stands of <i>C. amentacea</i> or <i>C. mediterranea</i> (a)	20
<i>Cystoseira crinitophylla</i>	Stands of <i>C. crinitophylla</i>	20
<i>Cystoseira crinita</i>	Stands of <i>C. crinita</i>	20
<i>Cystoseira corniculata</i>	Stands of <i>C. corniculata</i>	20
<i>Cystoseira foeniculacea</i>	Stands of <i>C. foeniculacea</i>	20
Coralline rims	Bioconstructions of <i>Lithophyllum byssoides</i> (b)	20
<i>Cystoseira barbata</i>	Stands of <i>C. barbata</i> without other <i>Cystoseira</i> species	16
<i>Cystoseira spicata</i> 2	Abundant patches of <i>C. amentacea</i> (a)	15
<i>Cystoseira compressa</i>	Stands of <i>C. compressa</i> without other <i>Cystoseira</i> species	12
<i>Cystoseira spicata</i> 1	Rare scattered plants of <i>C. amentacea</i> (a)	10
Photophilic algae	Communities dominated by <i>Padina</i> spp., <i>Dictyota</i> spp., <i>Dictyopteris</i> spp., <i>Taonia</i> spp. and <i>Halopteris</i> spp. (Phaeophyceae)	10
<i>Corallina elongata</i>	Community dominated by articulated Corallinales (c)	8
<i>Mytilus</i>	<i>M. galloprovincialis</i> (mussel) beds without <i>Cystoseira</i>	6
<i>Ulva</i> spp. and <i>Enteromorpha</i> spp.	Stands of <i>Ulva</i> spp. and <i>Cladophora</i> spp. (Chlorobionta) (d)	3
Cyanobacteria	Communities dominated by Cyanobacteria	1

234 (a) *Cystoseira spicata* and *C. amentacea* var. *spicata* are considered here as heterotypic synonyms of *C.*
235 *amentacea*. (b) We restricted this community type to bioconstructions of *L. byssoides*. (c) Several
236 species of articulated Corallinales, not distinguishable in the field, can occur in the Mediterranean Sea,
237 e.g. *Ellisolandia elongata* (synonym: *C. elongata*), *C. caespitosa* and *C. officinalis*. (d) The genus
238 *Enteromorpha* is no longer distinguished from the genus *Ulva*, to which *Enteromorpha* species belong.
239

240

241 In the present study, we propose another, alternative and simplified CARLIT index (hereafter:
242 simplified CARLIT method). The relevant geomorphological situations identified by
243 Ballesteros et al. (2007) according to the coastline morphology and natural/artificial substrates,
244 were not modified, except that only the last three relevant geomorphological situations were
245 taken into account on the basis of the principle that any artificial substrate will tend to be
246 colonized as a natural substrate over time (Table 2), although increased herbivory hinders the
247 colonisation by *Cystoseira* spp. (Gianni, 2016). Likewise, some modifications were made
248 regarding the communities mapped. The species and communities taken into account according
249 to a decreasing level of sensitivity (from 20, very sensitive, to 1, not sensitive) are listed in

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250 Table 6. In contrast to Ballesteros et al. (2007), *Cymodocea nodosa* meadows, *Zostera noltei*
 251 meadows, *Posidonia oceanica* reefs and *Lithophyllum byssoides* rims are no longer taken into
 252 account for the calculation. Except for these changes, the calculation method is still the same.

253

254 Table 6. Species and communities taken into account for the calculation of the new simplified
 255 CARLIT Index, and their 'sensitivity level' (SL).

Species and communities	Description in the study area	SL
<i>Cystoseira amentacea</i> / <i>C. mediterranea</i> 3	Continuous or almost continuous stands of <i>C. amentacea</i> or <i>C. mediterranea</i>	20
Other shallow <i>Cystoseira</i> spp.	Populations of <i>C. barbata</i> , <i>C. brachycarpa</i> , <i>C. crinita</i> , <i>C. foeniculacea</i> , <i>C. jabukae</i> (other than <i>C. amentacea</i> , <i>C. compressa</i> , <i>C. mediterranea</i>)	20
<i>Cystoseira amentacea</i> / <i>C. mediterranea</i> 2	Abundant patches of dense stands of <i>C. amentacea</i> or <i>C. mediterranea</i>	15
<i>Cystoseira compressa</i>	Continuous or almost continuous stands of <i>C. compressa</i> subsp. <i>compressa</i>	12
<i>Cystoseira amentacea</i> / <i>C. mediterranea</i> 1	Scattered plants of <i>C. amentacea</i> or <i>C. mediterranea</i>	10
Other soft macroalgae	Communities of non-perennial macroalgae without <i>Cystoseira</i> species, <i>Ulva</i> spp. and/or <i>Cladophora</i> spp. (including algal turf)	10
Articulated corallines	Stands of articulated <i>Corallina</i> spp. without <i>Cystoseira</i> species (e.g. <i>Corallina caespitosa</i> , <i>C. officinalis</i> and <i>Ellisolandia elongata</i>)	8
Encrusting corallines	Stands of <i>Lithophyllum incrustans</i> , <i>Neogoniolithon brassica-florida</i> and other encrusting corallines (Rhodophyta)	6
<i>Mytilus galloprovincialis</i>	<i>Mytilus galloprovincialis</i> (mussel) stands without <i>Cystoseira</i> species	6
Green macroalgae	Stands of <i>Ulva</i> spp. and/or <i>Cladophora</i> spp. (Chlorobionta)	3
Cyanobacteria	Communities dominated by Cyanobacteria (other than <i>Rivularia</i> sp.)	1

256

257 2.3. Calculation of the anthropogenic pressure indices

258 2.3.1. The Land Uses Simplified Index (LUSI)

259 The LUSI index was designed as a basis for analysing the relationship between the CARLIT
 260 results and the anthropogenic pressures. This index is based on a combination of factors that
 261 reflect continental influences in the coastal water bodies: (i) land uses (urban, industrial, and
 262 agricultural), (ii) the vicinity and the typology of rivers, and finally (iii) the shape of the coast
 263 (concave, convex or straight). The LUSI uses publicly available data. The calculation method
 264 of LUSI is described in Flo et al. (2011):

265

266 LUSI = (Urban Score + Agricultural Score + Industrial Score + Typology Score) *
267 Correction number

268 The scores were calculated taking into account a 1.5 km inland strip, within the limits of each
269 coastal WB, on a Corine Land Cover map based on 2006 data (Corine Land Cover, 2006).

270

271 2.3.2. *The MA-LUSI-WB index*

272 Torras et al. (2016) added two new descriptors to the calculation of the LUSI index: the
273 population pressure and the artificialization rate of the rocky shore. The population pressure
274 was estimated as the logarithm of the total population in the littoral municipalities divided by
275 the length of the coastline. The artificialization rate was calculated as the ratio of the total length
276 of artificial structures divided by the length of rocky shores.

277 The MA-LUSI-WB index of a coastal WB was calculated as follows:

$$278 \quad \text{MA-LUSI-WB} = \text{LUSI} + \log \left(\frac{\text{Inhabitants}}{\text{Coastline length}} \right) + \frac{\text{Length of artificial structures}}{\text{Length of rocky coastline}}$$

279

280 2.3.3. *The Cumulative Human Impacts Index*

281 The Cumulative Human Impacts Index (CHII) was proposed by Holon et al., 2015. It is based
282 upon a cumulative impact model, which takes into account 10 different pressures: man-made
283 coastline, boat anchoring, aquaculture, urban effluents, industrial effluents, urbanization,
284 agriculture, coastline erosion, coastal population and fishing.

285

286 2.3.4. *The Human Activities and Pressures Index (HAPI)*

287 To identify the pressures likely to have a real impact on the species and communities taken into
288 account in the CARLIT method, we propose here a new pressure index. Several criteria have
289 to be considered. To be considered, a pressure must concern the surface waters, must have an
290 obvious impact on the communities mapped and be persistent. Furthermore, data on pressures
291 must be available and representative at a coastal WB scale. Pressures observed at a single point

292 or at a scale of a few kilometres cannot be considered because they are not representative at the
 293 scale of a coastal WB. Thus, we listed three metrics of continental pressures (urban, industrial
 294 and agricultural areas) and four metrics of marine pressures.

295 For the continental pressures, the three considered metrics were expressed as the percentage of
 296 land area covered (data from Corine Land Cover, 2006) and were considered at the scale of the
 297 watershed of the coastal WB (in contrast with the LUSI index, which takes into account a 1.5
 298 km strip, whatever the coastal relief): (i) urbanisation (Corine Land Cover codes, CLC codes,
 299 111, 112, 141 and 142) (hereafter ‘Urban area’), (ii) industry (CLC codes 121 to 124 and 131
 300 to 133) (hereafter ‘Industrial area’), (iii) agricultural activities (CLC codes 211-213, 221-223,
 301 231 and 241-244) (hereafter ‘Agricultural area’).

302 The other areas without such pressures (e.g. forests) are considered as natural areas.

303 For the 4 marine pressures, we measured: (i) the artificialization of the coast (field data,
 304 expressed as the percentage of the artificialized coastline of the WB), (ii) fish farms (field data
 305 and Medtrix, 2015 (database IMPACT), expressed as the length of coastline of rocky coasts
 306 potentially impacted, in metres), (iii) sewage outfalls (field data and Medtrix, 2015 (database
 307 IMPACT), expressed as the length of coastline of rocky coasts potentially impacted, in metres)
 308 and (iv) rivers (field data and CARMEN 2015a, 2015b, expressed as the length of coastline of
 309 rocky coasts potentially impacted, in metres). Data from IMPACT are derived from modelling
 310 results (Holon et al., 2015). For the calculation of the pressure index, the ‘sewage outfalls’ and
 311 ‘rivers’ pressures were summed into a single pressure named ‘Freshwater’.

312

313 A semi-quantitative scale, between 1 and 4, was assigned for each pressure (Table 7).

314

315 Table 7. Pressure score (PS) assigned to each pressure *i*.

PS	Urban area (% watershed)	Industrial area (% watershed)	Agricultural area (% watershed)	Coastal artificialization (% shore length)	Fish farms (% shore length)	Freshwater (% shore length)
1	0 – 10	0 – 10	0 – 5	0 – 5	0 – 1	0 – 5
2	11 – 35	11 – 25	6 – 15	6 – 25	2 – 15	6 – 25
3	36 – 75	26 – 75	16 – 30	26 – 75	16 – 40	26 – 75
4	> 75	> 75	> 30	> 75	> 40	> 75

316

317

318 Each selected metric was correlated with the EQRs measured by the CARLIT method for each
 319 coastal WB. A Principal Component Analysis (PCA) was performed, using the software R® (R
 320 Core Team, 2013) to define the links between pressures and EQRs. An indication of the nature,
 321 strength and relevance of correlation is given to determine the prevailing trends in the data set.
 322 The correlation coefficients of these selected pressures were used to weight their influence in
 323 the calculation of the pressure index (Table 8).

324

325 Table 8. Absolute values of the correlation coefficient (r) between pressures *i* and the EQR data,
 326 from correlation matrix of the PCA

Pressure	Urban area	Industrial area	Agricultural area	Coastal artificialization	Fish farms	Freshwater
R	0.14	0.31	0.06	0.68	0.15	0.40

327

328 Finally, the pressure index of a WB was weighted according to the annual seawater turnover.
 329 The annual seawater turnover of a coastal WB can be derived from modelling (Ganzin et al.,
 330 2009). It represents the flow of water entering the water mass relative to the total volume of the
 331 WB, which accounts for the remanence of pollutants. We have distinguished three levels of
 332 annual seawater turnover rate and we assigned them three turnover scores (Table 9).

333 Table 9. Turnover score (TS) assigned to the annual seawater turnover rate of a WB *j*

Seawater turnover rate	TS
> 1 400	1.33
100 to 1400	1
< 100	0.80

334

335

336 The proposed pressure index (*Human Activities Pressures Index*; HAPI) for a coastal WB *j* is
 337 as follows:

$$338 \quad \mathbf{HAPI}_j = \sum (\mathbf{PS}_i * r_i) / \mathbf{TS}_j$$

339 where:

340 \mathbf{PS}_i : Pressure score assigned to the pressure *i* (Table 7).

341 r_i : absolute value of the correlation coefficient between the pressure *i* and EQR data (Table 8)

342 \mathbf{TS}_j : Turnover score assigned to the seawater turnover rate of the WB *j*.

343

344 The HAPI pressure index can vary from 1.31 (minimum pressure) to 8.70 (maximum pressure).

345

346 Each pressure index (LUSI, LUSI modified, Cumulative impact and HAPI) was correlated with
347 the EQR of each WB.

348

349 **3. Results**

350 **3.1. Ecological assessment**

351 The 40 coastal WBs surveyed represent ~2 970 km of coastline of rocky shores (measured at
352 1/2 500 scale).

353 For the first assessment of the 40 WBs, the three CARLIT indices gave very similar results
354 (Table 11): only three WBs changed their ES between the original CARLIT method and the
355 proposed simplified method (WB #5 from Poor to Moderate, WB #7 from High to Good and
356 WB #18 from Good to Moderate). When the WBs were assessed twice (23 WBs), 7 and 8 WBs
357 changed their ES (original and simplified CARLIT method, respectively) (Table 11).

358

359 Whatever the method, a significant correlation between the first and the second assessment was
360 observed ($r = 0.93$ for the original CARLIT index, $r = 0.89$ for the Nikolić index and $r = 0.89$
361 for the simplified CARLIT index, $p < 0.001$), indicating both robustness (reproducibility) and
362 the absence of trend.

363

364 Whatever the assessment (first or second), there is a significant correlation between the results
365 of the three methods ($r = 0.92$ between the original and Nikolić indices, $r = 0.95$ between the
366 original and the simplified CARLIT index and $r = 0.93$ between the simplified and the Nikolić
367 indices, $p < 0.001$).

368

369

370

371

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373

374

375

376 Table 11. Comparison of EQR values and ecological status of the 40 WBs (for number and
 377 administrative names, see Table 1 and Fig. 1), according to the three CARLIT indices
 378 (Ballesteros et al., 2007, Nikolić et al., 2013 and this study). EQR and ES column: first
 379 assessment (left) and second assessment (right).

Water bodies (WBs)	Original CARLIT index		Nikolić index		Simplified CARLIT index	
	EQR	ES	EQR	ES	EQR	ES
1 - FRDC01	0.52/0.58	Moderate Moderate	0.50/0.53	Moderate Moderate	0.47/0.56	Moderate Moderate
2 - FRDC02c	0.32/0.43	Poor Moderate	0.29/0.39	Poor Poor	0.32/0.43	Poor Moderate
3 - FRDC04	0.43/0.45	Moderate Moderate	0.40/0.41	Moderate Moderate	0.46/0.45	Moderate Moderate
4 - FRDC05	0.63/0.61	Good Good	0.58/0.61	Moderate Good	0.64/0.56	Good Moderate
5 - FRDC06a	0.36/0.43	Poor Moderate	0.40/0.40	Moderate Moderate	0.40/0.43	Moderate Moderate
6 - FRDC06b	0.55/0.64	Moderate Good	0.55/0.59	Moderate Moderate	0.47/0.54	Moderate Moderate
7 - FRDC07a	0.80/0.80	High High	0.74/0.71	Good Good	0.64/0.55	Good Moderate
8 - FRDC07b	0.95/0.85	High High	0.84/0.76	High High	0.76/0.64	High Good
9 - FRDC07c	0.66/0.57	Good Moderate	0.60/0.59	Moderate Moderate	0.61/0.57	Good Moderate
10 - FRDC07d	1.00/0.90	High High	0.94/0.82	High High	1.00/0.85	High High
11 - FRDC07e	0.76	High	0.76	High	0.77	High
12 - FRDC07f	0.93/0.94	High High	0.84/0.84	High High	0.93/0.93	High High
13 - FRDC07g	0.68/0.64	Good Good	0.64/0.62	Good Good	0.70/0.65	Good Good
14 - FRDC07h	1.00	High	0.96	High	1.00	High
15 - FRDC07i	0.64	Good	0.62	Good	0.65	Good
16 - FRDC07j	1.00	High	0.94	High	1.00	High
17 - FRDC08a	0.98	High	0.87	High	0.98	High
18 - FRDC08b	0.66/0.61	Good Good	0.55/0.45	Moderate Moderate	0.57/0.49	Moderate Moderate
19 - FRDC08c	0.54/0.55	Moderate Moderate	0.51/0.49	Moderate Moderate	0.55/0.55	Moderate Moderate
20 - FRDC08d	1.00/0.93	High High	0.99/0.83	High High	1.00/0.92	High High
21 - FRDC08e	0.82	High	0.75	Good	0.82	High
22 - FRDC09a	1.00	High	0.88	High	1.00	High
23 - FRDC09b	0.49/0.49	Moderate Moderate	0.43/0.43	Moderate Moderate	0.49/0.49	Moderate Moderate
24 - FRDC09c	1.00	High	0.92	High	1.00	High
25 - FRDC09d	0.36/0.43	Poor Moderate	0.31/0.42	Poor Moderate	0.36/0.44	Poor Moderate
26 - FRDC10a	0.81	High	0.71	Good	0.81	High
27 - FRDC10b	0.49/0.50	Moderate Moderate	0.44/0.49	Moderate Moderate	0.49/0.50	Moderate Moderate
28 - FRDC10c	0.72	Good	0.65	Good	0.72	Good
29 - FREC01ab	0.87	High	0.90	High	0.86	High
30 - FREC01c	0.58/0.69	Moderate Good	0.61/0.91	Good High	0.57/0.72	Moderate Good
31 - FREC01d	0.84/0.80	High High	0.91/0.82	High High	0.91/0.79	High High
32 - FREC01e	0.83	High	0.88	High	0.79	High
33 - FREC02ab	0.61/0.84	Good High	0.79/0.85	High High	0.60/0.85	Good High
34 - FREC03ad	0.80	High	0.87	High	0.82	High
35 - FREC03b	0.42/0.41	Moderate Moderate	0.46/0.47	Moderate Moderate	0.45/0.45	Moderate Moderate
36 - FREC03c	0.94	High	0.79	High	0.84	High

37 - FREC03eg	0.94	High		0.96	High		0.97	High	
38 - FREC03f	0.60/0.57	Moderate	Moderate	0.78/0.73	High	Good	0.58/0.58	Moderate	Moderate
39 - FREC04ac	0.96	High		0.96	High		0.96	High	
40 - FREC04b	0.88	High		0.89	High		0.90	High	

380

381 Considering the 23 WBs assessed twice, species and communities exhibited a relative stability
 382 between the two assessments ($r = 0.97$, $p < 0.001$). Only few changes in percentages of fast
 383 growing species or communities were recorded (mainly mussels, articulated corallines,
 384 encrusting corallines and other soft macroalgae) (Table 12), and 7 and 8 WBs changed their ES
 385 (mostly upgrade of one class) (original and simplified CARLIT indices, respectively) (Table
 386 11).

387

388 Table 12. Percentage of the shore length occupied by the species and communities taken into
 389 account for the calculation of the CARLIT index over 23 water bodies assessed in 2007-2010
 390 and in 2012-2015.

Species and communities	First assessment (2007-2010)	Second assessment (2012-2015)
<i>C. amentacea</i> and <i>C. mediterranea</i> (3, 2 and 1)	38.0	39.5
Other shallow <i>Cystoseira</i> spp.	0.1	1.2
<i>Cystoseira compressa</i>	2.2	3.0
Other soft macroalgae	3.9	6.4
Articulated corallines	20.5	26.8
Encrusting corallines	12.5	7.3
<i>Mytilus galloprovincialis</i> (mussels)	6.9	2.8
Green macroalgae	3.1	3.1
Cyanobacteria	4.9	3.0
<i>Lithophyllum byssoides</i> rim	7.9	6.9

391

392

393 3.2. Response of CARLIT indices to anthropogenic pressures

394 Values of each anthropogenic pressure index have been calculated for the 40 water bodies
 395 (Table S1).

396

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397 Correlations between the three CARLIT indices and the different pressure indices were not
 398 significant with the CHII, slightly correlated with LUSI and MA-LUSI-WB, and strongly
 399 correlated with the HAPI (Table 13).

400

401

402

403 Table 13. Correlation between the EQR values, according to each CARLIT index, and the four
 404 anthropogenic pressures indices. * significant ($p < 0.05$).

	EQR Original CARLIT index	EQR Nikolić index	EQR Simplified CARLIT index
LUSI Index	-0.33*	-0.05*	-0.25
MA-LUSI-WB	-0.39*	-0.57*	-0.33*
CHII	-0.07	-0.06	+0.07
HAPI	-0.79*	-0.86*	-0.74*

405

406

407 **4. Discussion**

408 The present data constitute the most extensive assessment ever undertaken of the ecological
 409 status of Mediterranean waters, based upon the CARLIT index, the most widely used index for
 410 the Mediterranean Sea (Table 14). This assessment encompasses 40 coastal water bodies and
 411 ~2 970 kilometres of shore (at 1/2 500 scale).

412 The simplified CARLIT index, proposed here, does not significantly save field time, and
 413 provides less accurate mapping of the communities (Enric Ballesteros pers. comm.), but is
 414 easier to implement and requires less expert judgement than the original method (Ballesteros et
 415 al., 2007). As highlighted by Dauvin et al. (2010), the benthic indicators have to be transferred
 416 in the simplest possible form to local authorities, such as marine protected areas (MPAs). In
 417 addition, the simplified index provides results similar overall to those of the original method;
 418 when changes occur, they consist in a slight lowering of the EQR; this is due to the removal of
 419 *Lithophyllum byssoides* rims (e.g. WB #7 where *L. byssoides* rims are very abundant). These
 420 rims were indicative of a long period of good ES in the past, but are currently undergoing
 421 submersion and collapse because of the sea level rise (Verlaque, 2010; Faivre et al., 2013;
 422 Thibaut et al., 2013). This trend is expected to increase in the next few years, and it is thus

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423 difficult to separate the impact of sea level rise from that of the water quality, obviously
424 resulting in a bias in future assessments.

425 Two successive assessments were performed (2007-2010 vs 2012-2015). The results were very
426 similar and, when there was a change in EQR, the simplified CARLIT index does not evidence
427 a unidirectional trend. Cavallo et al (2016) already stressed the robustness of the CARLIT
428 method. In addition to robustness, the significant high correlation between the two assessments,
429 whatever the method, evidences the stability of the overall ES of the coastal water bodies.
430 Consequently, as suggested by Cavallo et al. (2016), successive assessments could be carried
431 out at low frequency.

432 The existing EQRs were mainly based upon the expert knowledge of the sensitivity of species
433 and communities to a set of anthropogenic stressors. Most of these EQRs have not been
434 correlated with definite pressures, or have been empirically linked to ill-defined pressures.
435 Interesting attempts have been made to link EQRs and pressures (e.g. Mangialajo et al., 2007;
436 Orlando-Bonaca et al., 2008; Iveša et al., 2009; Díez et al., 2012; Neto et al., 2012; Bermejo et
437 al., 2012, 2013; Nikolić et al., 2013; Guinda et al., 2014a; Ar Gall et al., 2016). However, some
438 of the stressors were often tackled on the basis of scattered measurements, were spatially and/or
439 temporally very variable, were not representative of all the WBs and/or their impact upon
440 species and communities was far from being established. Stressors such as turbidity, dissolved
441 organic nitrogen, phosphate, Chlorophyll-*a*, saturated O₂, faecal bacterial indices, etc., may
442 prove to be irrelevant in the framework of the WFD, at least in some WBs, for one or several
443 of the above-mentioned reasons. This is illustrated by general indices, such as CHII (Holon et
444 al., 2015); although very comprehensive and useful in contexts other than that of the WFD, it
445 is totally uncorrelated with the CARLIT index. To date, the LUSI and the MA-LUSI-WB were
446 the best and most widely used pressure indices, the former being the recommended pressure
447 index in the context of the Mediterranean Geographical Intercalibration Group (Buché, 2012).
448 The main shortcoming of the LUSI index is that it is only based upon the land and river estuaries
449 (Flo et al., 2011). The MA-LUSI-WB (Torrás et al., 2016) improves on the LUSI index by
450 adding the length of artificial structures along the shore. Here, we have proposed a new pressure
451 index (HAPI), taking into account the possible shortcomings of previous indices; this pressure
452 index accounts better for the EQR values than the previous indices, as evidenced by the high
453 correlation coefficient between EQR and HAPI.

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454 Data collected in the framework of CARLIT method provide a mapping of species or
455 communities present on the rocky shores and ultimately the ecological status of one water body
456 at a given time. The link between the CARLIT index and HAPI index provides an understanding
457 of the link between the ecological status and anthropogenic pressures of a water body. The
458 HAPI index could be used to define switching thresholds between ecological statuses and
459 quantify the ‘maximum load’ for each pressure in each water body. Identification of pressures
460 impacting the communities and determining the switching threshold will allow managers to act
461 at the source of the pressure and prevent or limit the deterioration or improve the ecological
462 quality of water bodies, which is one of the objectives of the WFD.

463 The CARLIT index, especially when coupled with a pressure index, constitutes a powerful tool
464 in the framework of the WFD. However, in the context of the MSFD policy (Council Directive,
465 2008), it must be completed by new indicators taking into account the whole water column and
466 the ecosystem functioning, such as the Ecosystem-Based Quality Indices (EBQI) (Personnic et
467 al., 2014; Ruitton et al., 2014; Rastorgueff et al., 2015).

468 The Mediterranean Sea is often regarded as a sea that is highly impacted by a variety of human-
469 induced stressors, e.g. artificialization of the coast, discharges from sewage outfalls and rivers,
470 fish farms (e.g. Pergent-Martini et al., 2006; Halpern et al., 2008; Lejeusne et al., 2010; Meinesz
471 et al., 2013; Micheli et al., 2013; Giakoumi et al., 2015; Holon et al., 2015). The present study
472 significantly increases the available number of coastal water bodies assessed with the CARLIT
473 method and now provides a comprehensive view along thousands of kilometres of shore.
474 Surprisingly, the picture is far less a cause for concern than initially expected, at least in the
475 western Mediterranean basin (Table 14). This can be related to the recent improvement of the
476 water quality (Pinedo et al., 2013) as a result of the European water policy. There is also a
477 possibility that the situation of the Mediterranean WB, better than expected, may be an artefact
478 due to the focus on superficial waters and habitats inherent to the CARLIT method. If so, this
479 artefact should be corrected by the complementary indices developed in the framework of the
480 MSFD. Overall, as stressed by Enric Ballesteros (pers. comm.), the problems of the
481 Mediterranean Sea are more related to habitat loss, overfishing, invasive species, etc., which do
482 not per se affect the water quality at a water body level (although they can affect it at a more
483 local scale).

484

485 5. Conclusion

486 As a result of the present study, undertaken at a geographical scale never previously attempted,
 487 a comprehensive picture of a broad range of WBs is now available. The pertinence of the
 488 method, and of its improvement proposed here, has been confirmed, through several pressure
 489 indices, one of them (HAPI) being an original proposal. In fact, considering the complexity of
 490 the Integrated Coastal Zone Management (ICZM), no single index can account for such a
 491 diversity of issues: the ecological quality of a WB as a whole, status of the ecosystems, natural
 492 and human-induced pressures, etc. The future of the ICZM requires a combination of indices,
 493 each one providing information regarding a given problem, parameter and/or ecosystem, at a
 494 given scale.

495 Future developments of the relationship between WB quality and ecological indicators on the
 496 one hand, and between CARLIT indices and stressors, could take advantage of the use of
 497 mathematical methods and models such as those developed in the framework of other scientific
 498 fields (e.g. Ocampo-Duque et al., 2006; Zhao et al., 2006; Muttill and Chau, 2007; Wang et al.,
 499 2014).

500

501

502 Table 14. Comparison of the ecological status of coastal water bodies in different Mediterranean
 503 regions, based upon the CARLIT method sensu lato. Percentage of coastal water bodies falling
 504 within each category (High through Bad) and the total number of WB analysed.

Study area	High	Good	Moderate	Poor	Bad	Total	Reference
Alboran Sea (Andalusia, Spain)**	55	30	10	5	0	20	Bermejo et al., 2013
Catalonia (Spain)	16	27	46	12	0	33	Ballesteros et al., 2007
Catalonia (Spain)	22	22	53	3	0	32	Torras et al., 2016
France (Ballesteros original method)*	55	18	28	0	0	40	This study
France (Nikolić method)*	50	20	28	3	0	40	This study
France (Simplified method)*	50	13	38	0	0	40	This study
Liguria (Italy)**	33	33	25	8	0	12	Asnaghi et al., 2009
Genova-Portofino area (Liguria, Italy)**	33	33	33	0	0	3	Mangialajo et al., 2007
Capo Carbonara MPA (Sardinia, Italy)**	100	0	0	0	0	2	Ferrigno et al., 2014

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Malta	78	11	11	0	0	9	Blanfuné et al., 2011
Eastern Adriatic Sea (Croatia)**	67	0	0	17	17	6	Nikolić et al., 2013
District of Vlora (Albania)	40	0	20	20	20	5	Blanfuné et al., 2016

505 * Last Ecological status obtained for each coastal water bodies

506 ** not water bodies but site

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508

509

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800 Table S1. Anthropogenic pressure indices for each WB (number and administrative name).

Water bodies (WBs)	Anthropogenic pressure Index			
	LUSI Index	MA-LUSI-WB	CHII	HAPI
1 - FRDC01	3.75	4.733	185 865	2.65
2 - FRDC02c	3.00	4.727	133 758	5.04
3 - FRDC04	5.00	6.390	987 027	4.76
4 - FRDC05	2.00	3.232	281 824	3.46
5 - FRDC06a	5.00	7.320	147 829	5.55
6 - FRDC06b	2.00	3.412	201 066	3.15
7 - FRDC07a	0.00	1.336	44 930	2.57
8 - FRDC07b	1.25	2.582	131 416	2.61
9 - FRDC07c	1.25	2.692	180 446	3.78
10 - FRDC07d	2.50	3.568	51 202	2.42
11 - FRDC07e	2.50	3.737	328 887	3.50
12 - FRDC07f	3.75	4.966	397 703	3.50
13 - FRDC07g	3.75	5.354	372 188	4.57
14 - FRDC07h	2.50	3.448	305 718	1.77
15 - FRDC07i	5.00	6.539	441 896	4.54
16 - FRDC07j	2.50	3.472	381 960	2.93
17 - FRDC08a	5.00	6.169	300 741	2.80
18 - FRDC08b	6.25	7.781	258 084	4.20
19 - FRDC08c	6.25	8.283	93 169	5.83
20 - FRDC08d	2.00	2.977	195 065	2.41
21 - FRDC08e	5.00	6.397	470 680	3.57
22 - FRDC09a	3.00	4.375	28 182	2.27
23 - FRDC09b	3.75	5.849	220 360	5.28
24 - FRDC09c	3.75	5.236	11 319	1.64
25 - FRDC09d	3.75	5.128	31 146	4.48
26 - FRDC10a	3.75	4.951	151 730	2.73
27 - FRDC10b	3.75	5.821		5.39
28 - FRDC10c	1.50	3.030		4.43
29 - FREC01ab	1.25	2.063	432 929	1.77
30 - FREC01c	1.25	2.128	142 886	2.19
31 - FREC01d	0.00	0.642	54 936	1.73
32 - FREC01e	1.25	1.923	69 108	1.73
33 - FREC02ab	2.00	2.921	234 051	1.77
34 - FREC03ad	2.50	3.341	147 395	1.77
35 - FREC03b	2.50	3.682	479 838	4.19
36 - FREC03c	1.25	2.188	19 156	2.07
37 - FREC03eg	0.00	0.813	201 776	1.81
38 - FREC03f	1.25	2.235	4 367	3.45
39 - FREC04ac	2.50	3.391	708 705	1.77
40 - FREC04b	1.25	2.309	405 107	2.88

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