



A DAPSI(W)R(M) framework approach to characterization of environmental issues in touristic coastal systems. An example from Southern Spain.

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1 **A DAPSI(W)R(M) framework approach to characterization of environmental issues in touristic**
2 **coastal systems. An example from Southern Spain.**

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4 Cooper.

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6 **Abstract**

7 Coasts are complex natural and human systems subject to change via natural processes and human
8 activity. Assimilation of this diverse set of drivers and responses and the relationships between them
9 is a challenge in coastal management. We investigate the utility of the DAPSI(W)R(M) framework to
10 identify indicators of environmental issues and the relations between human activities and the
11 environment through a practical application on a coast with high levels of tourism-related activities.
12 Components and indicators were assessed by a review of literature and existing data in the Málaga
13 Province of southern Spain, focusing on coastal erosion and its relationship to the natural
14 environment and social systems. The results indicate the utility of the DAPSI(W)R(M) framework to
15 characterize key environmental issues that affect coastal areas, and provide an holistic vision of
16 human activities and environmental processes. The application of this approach can improve coastal
17 management through the development of a simple model that characterizes environmental issues
18 from the causes to the consequences by means of indicators and the relationships between them.
19 The cyclic form of the model permits an easy identification of where problems occur and who is
20 involved with their resolution, helping with stakeholder mapping and decision-making regarding
21 appropriate responses, that can be taken to other administrative levels or other heavily developed
22 tourist coastal areas.

23

24 **Keywords**

25 DPSIR framework; coastal environments; coastal erosion; Costa del Sol, Málaga Province

26

1. Introduction

27 Understanding the diverse set of natural and human factors that being part of coastal systems and
28 relationships between them is a challenge in coastal management. Coastal and marine
29 environments are complex systems affected by numerous interrelated physical, chemical and
30 biological processes (Davis, 1985; Elliott et al., 2017; Patricio et al., 2016) being the beach and
31 nearshore zone the most dynamic parts of those systems (Davis, 1985). The risk of coastal
32 erosion/flooding is a problem in many developed coastal areas (Cooper and Lemckert, 2012; Rangel-
33 Buitrago et al., 2015) and the associated changes in coastal environments impact their biodiversity,
34 landscape and human interests.

35 Coasts therefore constitute valuable human environments that are threatened both by natural
36 processes and human pressure (Cooper et al., 2020; Cooper and Alonso, 2006), especially in areas
37 with coastal tourism – one of the world’s largest industries (Klein et al., 2004), exacerbated by sea-

38 level rise and other climatic change-related processes (Anfuso et al., 2020; Komar and Allan, 2008).
39 Over 70% of global shorelines are retreating (Bird, 2011).

40 In recent decades, several frameworks have been developed to assess environmental problems.
41 These approaches differ considerably depending on the area of knowledge of the scientists involved.
42 In terms of vulnerability studies, the widely used Coastal Vulnerability Index (CVI) (Barnett and
43 Adger, 2003; Dominguez et al., 2005; Gornitz, 1990; McLaughlin et al., 2002; McLaughlin and
44 Cooper, 2010) assesses coastal vulnerability as a function of coastal characteristics, coastal forcing
45 and socio-economic variables. The recent Index of Social and Morphological Vulnerability (ISMV)
46 proposed by Bianco and García-Ayllón (2021), defined by the authors as “*a mixed approach to*
47 *calculate vulnerability assessment from a comprehensive point of view*”, integrates three sub-
48 indices: the Index of Morphological Variation (IMV), the Index of Services’ Cost (ISC) and the Index
49 of Coastal Regeneration (CRI) to assess the resilience of the studied area. From a system point of
50 view, the Ecosystem Services (ES) framework (Boumans et al., 2002; Limburg et al., 2002), originally
51 developed for biology and botanical science and ecological economics, translates the basic
52 ecological structures and processes into value-laden entities for assessment of ecosystem functions
53 (de Groot et al., 2002). The Social-Ecological Systems framework (SESF) (Ostrom, 2009, 2007)
54 applied mainly for the management of forestry, fishery and water resources, consists of an extensive
55 multi-tier hierarchy of variables relevant to the analysis of social-ecological systems. The Systems
56 Approach Framework (SAF) (Hopkins et al., 2011), a product of the SPICOSA (Science and Policy
57 Integration for Coastal Systems Assessment) project (<http://www.spicosa.eu/index.htm>) and
58 further developed in the BONUS BaltCoast Project (<https://www.baltcoast.net/>), provides a six-step
59 process from the identification of an issue to the implementation of policy decisions that involves
60 the participation of stakeholders with the aim to facilitate the implementation of European
61 environmental policies while achieving sustainable development (Newton, 2012).

62 The Driver, Pressure, State, Impact, Response (DPSIR) framework, developed by the Organization of
63 Economic Cooperation and Development (OECD, 1993) and the European Environmental Agency
64 (European Environment Agency, 1999), is a tool for the adaptive management of the social-
65 ecological systems (Gari et al., 2015) that evolved from other frameworks that have been developed
66 to identify environmental issues following a causality chain, such as the Stress-Response (S-R)
67 framework (Rapport and Friend, 1979) or the Pressure State Response framework (PSR) (OECD,
68 1991). In the DPSIR framework, the five categories, i.e. drivers, pressure, state, impact and response,
69 are represented by environmental indicators that are connected following a sequence and may
70 involve feedback loops.

71 The DPSIR framework (see below) has been widely used to assess the consequences of human
72 actions on coastal ecosystems (Bruno et al., 2020; Semeoshenkova et al., 2017; Silva et al., 2020).
73 However, in recent years, several authors have modified the original scheme and clarified some
74 definitions. Gari et al. (2015) and Lewinson et al. (2016) reviewed many publications about the
75 application of DPSIR in coastal and marine areas, highlighting important differences on interpreting
76 definitions and giving examples of different modifications of the original DPSIR scheme. Patricio et
77 al. (2016) described the full evolution of DPSIR framework up to the latest version DAPSI(W)R(M)

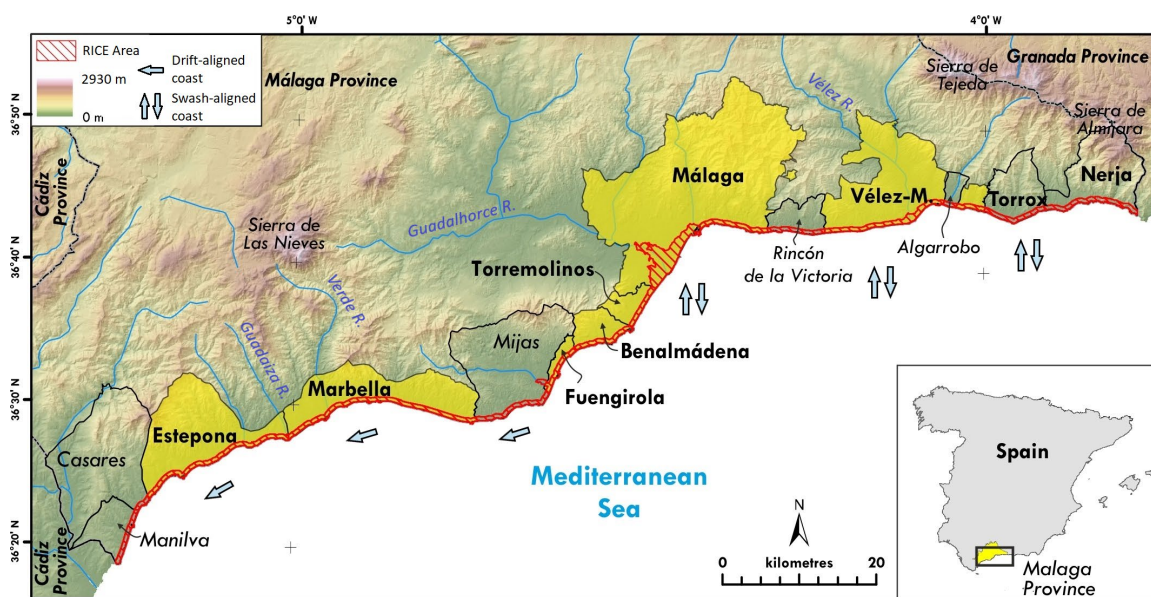
78 (Scharin et al., 2016) based on the previous iteration proposed by Smyth et al. (2015) that, in turn
79 followed the Elliot (2014) version.

80 The aim of this paper is to test the suitability of the DAPSI(W)R(M) approach to characterize diverse
81 environmental issues in touristic coastal areas. This requires selection of environmental indicators
82 that reflect all elements of the chain linking human activities, their environmental impacts, and the
83 societal response to such impacts. The implications for coastal management are explored.

84 The Málaga Province coast of Spain was chosen as a study site because of its high-intensity tourism-
85 related development. The DAPSI(W)R(M) tool was applied to identify the main factors that
86 cause/enhance coastal erosion and flooding and the relationships between them in urbanised
87 tourist areas. The DAPSI(W)R(M) framework provides a complete vision of human activities and
88 environmental processes within a specific scenario because factors are distributed among different
89 categories and each one occupies a specific position within the cyclic sequence proposed by this
90 methodology.

91 2. Study area

92 The coast of Malaga Province (tidal range < 0.2 m) comprises rocky sectors alternating with sand or
93 pebble beaches. In recent decades, river basin regulation related to water management for tourism
94 and agriculture has led to construction of dams, reduced sediment supply to the coast and
95 consequent shoreline retreat (Guisado et al., 2013; Molina et al., 2019a).



96
97 Figure 1. Location of the study area. The administrative subdivisions of the municipalities are
98 outlined on the map, with those selected in the study being shaded yellow.

99 Large coastal towns include Málaga (>500,000 inhabitants) and the tourist towns of Marbella (ca.
100 150,000 inhabitants), Fuengirola (ca. 80,000) and Torremolinos (ca. 70,000). The coastline is highly
101 developed due to the construction of tourism infrastructure (DGPC. Dirección General de Puertos y

102 Costas, 1991). Commercial ports are located at Almería, Algeciras, Cádiz and Málaga, and there are
103 several marinas (Malvárez García et al., 2003; Manno et al., 2016).

104 The Costa del Sol is internationally renowned for tourism (Malvárez, 2012) and tourist infrastructure
105 development in the 1960s, without rational spatial planning, resulted in a population increase and
106 transformation of the coastal landscape. Although those developments produced economic
107 benefits they also had major environmental impacts (loss of sand from beaches, large-scale
108 alteration of river basins, pollution of aquifers, construction of coastal defense infrastructure, etc.)
109 due to the intensive urbanization (Guisado et al., 2013).

110 The majority of the coastal protection structures were emplaced on tourist beaches in order to
111 counter coastal retreat or enlarge the dry beach width to make them more attractive for tourists.
112 These decisions are often taken under pressure from owners of newly constructed expensive
113 properties (Guisado et al., 2013). Before the Coast Law of 1988, hard protection structures were
114 implemented without control, under the action-reaction criteria (Guisado et al., 2013; Manno et al.,
115 2016), e.g. the implementation of new structures in down-drift areas to counteract erosion caused
116 by existing structures (Cooper et al., 2009).

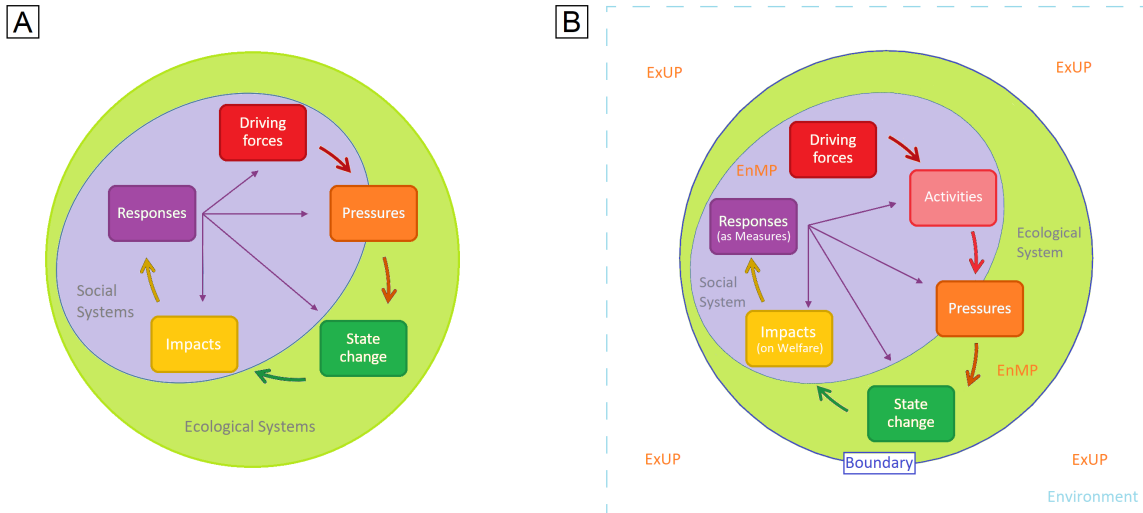
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118 The coast of Malaga province is generally exposed to winds blowing from E to W, with minimum
119 and maximum velocities ranging from 0.4 to 9.0 m/s (Molina et al., 2019b) and waves, which show
120 a clear seasonal behavior, approaching from western and eastern directions (Molina et al., 2020b,
121 2019b). Storm conditions, which can have a great impact on both natural and urbanized sectors
122 (Molina et al., 2019b), are recorded during November–March, i.e., the winter season (Guisado et
123 al., 2013; Molina et al., 2019b; Pita López, 2003), with mean values of significant wave height that
124 reaches 5.18 m during extreme storm conditions (Molina et al., 2019b).

125 Due to shoreline orientation, predominant easterly winds and associated storm waves give rise to a
126 prevailing westward littoral drift (Guisado et al., 2013; Pita López, 2003). In the center and eastern
127 coast of the province Málaga a large swash-aligned area was identified that results from a
128 bidirectional longshore transport and/or a cross-shore transport. A drift-aligned sector,
129 characterized by a unidirectional longshore transport, was recorded on the western coast (Figure 1)
130 (Molina et al., 2019a).

131 **3. Methods**

132 The DPSIR analytical framework helps the identification of indicators used to describe an
133 environmental issue and the relationships between human activities and the environment. From a
134 systems analysis perspective it is a model that describes a dynamic situation where *“social and
135 economic developments exert pressure on the environment and, as a consequence, the state of the
136 environment changes. This leads to impacts on e.g. human health, ecosystems and material that
137 may elicit a societal response that feeds back on the driving forces, on the pressures or on the state
138 or impacts directly”* (European Environment Agency, 2003) (Figure 2A).



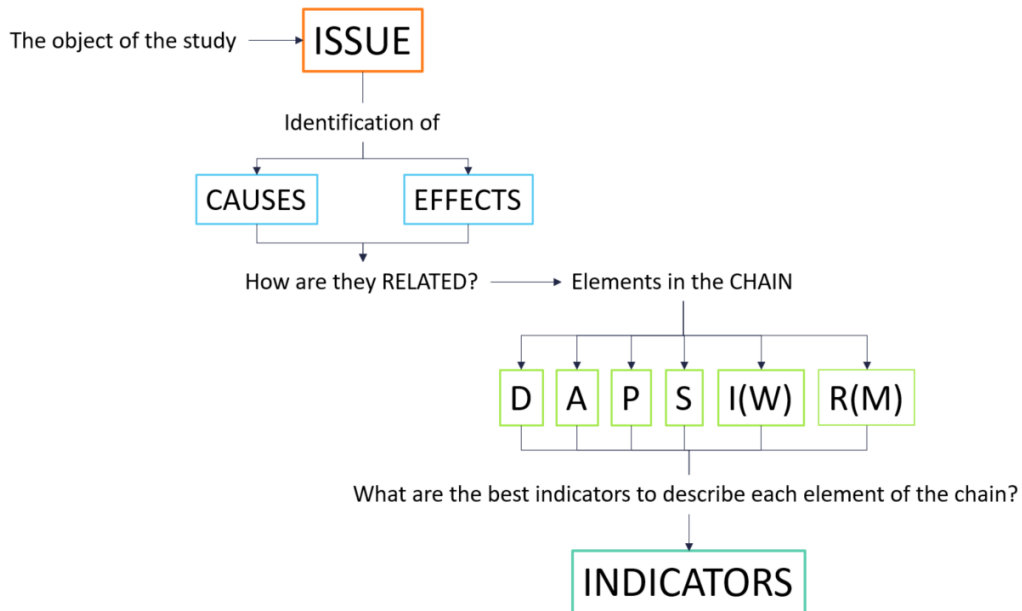
139

140 Figure 2. The original DPSIR (a) and the DAPSI(W)R(M) (b) frameworks.

141 The DPSIR framework identifies cause-effect relations between anthropogenic activities and their
 142 environmental and socio-economic consequences (Gari et al., 2015). It brings together natural
 143 science and social science including economics in a single framework and it views human activities
 144 as an integral part of the ecosystem (Zaldívar et al., 2008). It is considered a useful adaptive
 145 management tool for analyzing and identifying solutions to environmental problems (Gari et al.,
 146 2015).

147 The framework uses indicators to communicate the most relevant features of the environment and
 148 other issues, and these indicators should reflect all elements of the chain between human activities,
 149 their environmental impacts, and the societal responses (European Environment Agency, 2003). The
 150 original DPSIR scheme evolved because several authors encountered difficulties when interpreting
 151 it (Elliott and O’Higgins, 2020; Patricio et al., 2016; Scharin et al., 2016). Here, the latest version
 152 DAPSI(W)R(M) (Scharin et al., 2016), proposed by Smyth et al. (2015) was used (Figure 2B) and the
 153 official definitions (European Environment Agency, 2003) of the original DPSIR framework indicators
 154 were used according with the most recent modifications (Boyes and Elliott, 2015, 2014; Cooper,
 155 2013, 2012; Elliott, 2014; Elliott et al., 2017, 2006; Gari et al., 2015; Langmead et al., 2007; O’Higgins
 156 et al., 2014; Scharin et al., 2016).

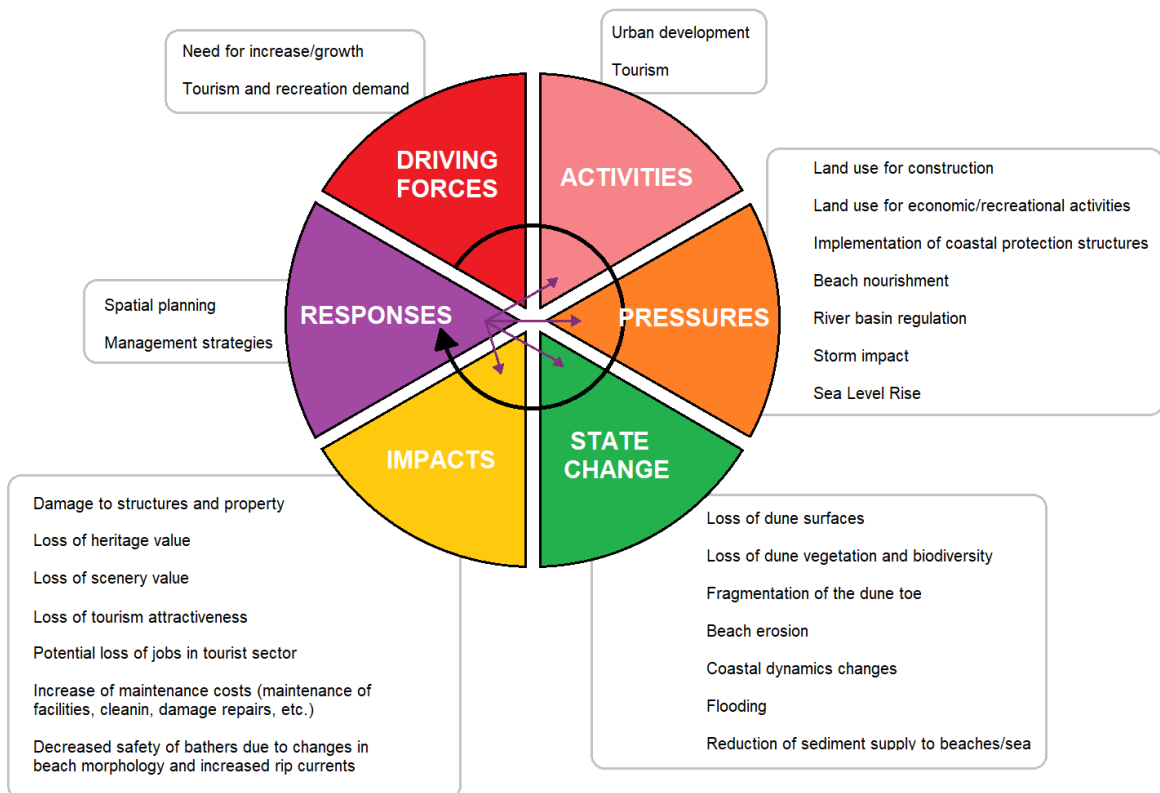
157 In this paper, the components and indicators of the DPSIR cycle modified into DAPSI(W)R(M) were
 158 assessed by a comprehensive review of literature and data (Table 1 and 2). Figure 3 schematically
 159 shows how the indicators for each element of the DAPSI(W)R(M) chain are obtained.



160

161 Figure 3. Schematic summary of the process followed to obtain the indicators used to carry out the
 162 required analysis according to the DAPSI(W)R(M) framework.

163 This paper focuses on the relations between coastal erosion and its associated effects on the
 164 environment and social systems. The indicators used in this work are summarized in Figure 4.



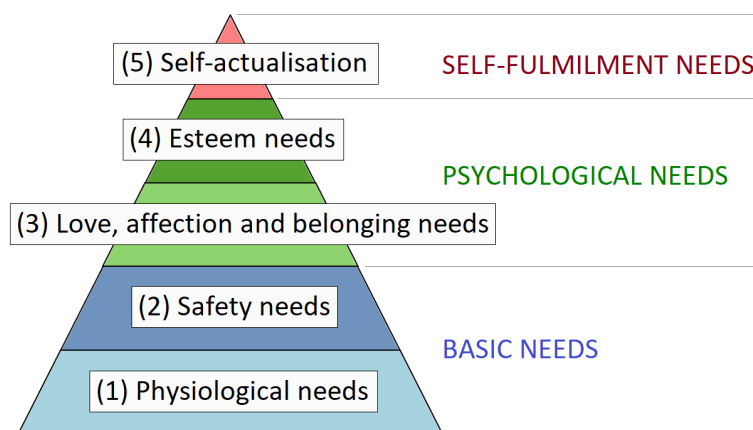
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166 Figure 4. Indicators proposed in this paper within the DAPSI(W)R(M) diagram. Storm impact and SLR
167 were considered pressures as they are due to climate change, and the current consensus is that
168 human activities produce greenhouse gases that contribute to climate change (Gari et al., 2015).

169 3.1. Driving forces or Drivers (D)

170 These describe the social, demographic and economic developments in societies and changes in
171 lifestyles, levels of consumption and production patterns. Changes in the driving forces, considered
172 as the main demands of the system, exert pressure on the environment. Due to the low clarity of
173 their definition, Drivers were often interpreted as activities or sectors (Patricio et al., 2016) and
174 natural and social scientists interpreted them in a different way, *i.e.* social scientists refer to drivers
175 as basic human needs and natural scientists regard them as activities (Elliott and O’Higgins, 2020).
176 For this reason, in the DAPSI(W)R(M) framework, these two interpretations were separated into
177 two different steps in the cycle: Drivers are now interpreted as basic human needs or demands
178 whose satisfaction leads to Activities, as the next step in the cycle (Elliott, 2014; Smyth et al., 2015).
179

180 Following Elliot et al. (2017), the Maslow’s hierarchy of basic needs (Maslow, 1943) can be used to
181 determine the drivers, *i.e.* human needs, and this then leads to the different activities implied in the
182 issues that have to be studied (Figure 5).



183
184 Figure 5. Maslow’s hierarchy of human needs (Maslow, 1943) adapted from Elliot and
185 O’Higgins (2020).

186 This five-tier hierarchical scheme can be summarized into three kinds of human needs:

- 187 - Basic needs: (1) Physiological and (2) safety needs. The first refers to the human needs to
188 survive (e.g. air, food, drink, sleep), and the second refers to safety and security (e.g.
189 protection of elements, security, stability, freedom from fear).
- 190 - Psychological needs: (3) Love, affection and belonging and (4) esteem needs. These needs
191 refer to psychological and emotional aspects. The first refers to needs such as friendship,
192 intimacy or trust, and the second refers to self-respect or prestige, among others.
- 193 - Self-fulfilment needs: (5) Self-actualisation or self-fulfilment, which refers to the desire of a
194 human to realise their potential or become everything that one is capable of becoming.

195 All of these human needs influence the way the space and goods are used and the competition
196 between individuals, societies and nations, and the satisfaction of these needs are the forces that

197 drive the development of activities involving a range of social interactions between humans and the
198 environment (Elliott and O’Higgins, 2020).

199 In this work, the selected indicators for Drivers were “Need for increase/growth” and “Tourism and
200 recreation demand”.

201 3.2. Activities (A)

202 Once activities and human demands are separated from the original Drivers definition, Activities
203 refers to what we do in order to satisfy human demands or basic needs, and these human
204 interventions create one or more Pressures on the system (Elliott, 2014; Smyth et al., 2015)

205 Indicators for these activities were obtained by a cause-effect relation from the selected Drivers
206 indicators. The selected indicators for Activities were “Urban development” and “Tourism”.

207 Data provided by IECA, the Institute of Statistics and Cartography of Andalusia (*Instituto de*
208 *Estadística y Cartografía*, Junta de Andalucía,
209 <https://www.juntadeandalucia.es/institutodeestadisticaycartografia>, accessed on March 2022)
210 were used to valuate the forementioned indicators, specifically the increase of population, the
211 distribution of urban cells and the area occupied by buildings (data for “Urban development”), and
212 the number of regulated tourist establishments and beds, the number of tourists and their
213 distribution per trimester (data for “Tourism”).

214 3.3. Pressures (P)

215 Pressures describe developments involving release of substances, physical and biological agents,
216 the use of resources and the use of land by human activities. The pressures are then the mechanisms
217 that result in changes in environmental conditions. Two kinds of pressures can be distinguished
218 following Elliot (2011): i) Exogenic Unmanaged Pressures (ExUP), which originate outside the
219 managed area and cannot be managed at that scale, or ii) Endogenic Managed Pressures (EnMP),
220 which occur inside the managed area and whose causes can be managed. An example of the former
221 is Sea Level Rise as a consequence of global climate change, whose consequences can only be
222 treated at the regional scale. An example of the latter case is the implementation of a hard coastal
223 protection structure, e.g. a groin, where both causes and consequences can be managed locally.

224 Following the cause-effect chain of the DPSI(W)R(M) framework, indicators used to quantify
225 pressures in this paper are, as EnMP, “Land use for construction”, “Land use for
226 economic/recreational activities”, “Implementation of coastal protection structures”, “Beach
227 nourishment”, “River basin regulation” and, as ExUP, “Storm damage” and “Sea Level Rise”. Table 1
228 summarizes the methodology used to obtain the associated data.

229 Table 1. Synthesis of the methodology used to obtain the Pressures indicators used in this paper.

Type	Indicator	Methodology
Pressure	“Land use for construction” and “Land use for economic/recreational activities”	Data provided by CLC (2018, 2006) - the typology and percentage of territory occupied by urbanized areas in the selected municipalities in 2006 and 2018. Identifying:

	<ul style="list-style-type: none"> - urbanized/industrialized index (URICE) - urban areas in RICE expressed as percentage of the total RICE area - land use for economic/recreational activities (ERICE) - urban areas used for economic/recreational activities in RICE expressed as percentage of the urbanized/industrialized area (URICE) <p>The concept and procedures for the RICE area calculations are developed below.</p>
“Implementation of coastal protection structures”	<p>Based on the study of coastline armoring along the Mediterranean coast of Andalusia developed by Manno et al. (2016) for 1956, 1977, 2001 and 2010.</p> <p>To quantify the progressive implementation of coastal structures, the length of armored coastline at each locality, expressed in km per year, was calculated for 1956 and 2010.</p>
“Beach nourishment” and “River basin regulation”	<p>Systematic data on beach nourishment works and river basin regulations were not available - just a few documents exist</p>
“Storm impact”	<p>This was determined using the wave energy flux data derived by Molina et al. (2020b) for the two prevailing storm conditions, (Guisado et al., 2013; Guisado-Pintado et al., 2014; Malvárez et al., 2019; Molina et al., 2020b, 2019b).</p> <p>The Energy Flux parameter represents the power of the storm per unit of wavelength because it takes into account both storm duration and wave height (Lo Re et al., 2019). It is the output of a wave propagation process and therefore reflects several cumulative factors determining the way in which wave energy is distributed along the coastline (e.g., wave exposure and local bathymetric characteristics).</p>
“Sea Level Rise”	<p>Sea level trend and projections were obtained from the Copernicus Program (https://www.copernicus.eu/en), the European Centre for Medium-Range Weather Forecasts (ECMWF, https://www.ecmwf.int/) and the Spanish Ports State agency <i>Puertos del Estado</i> (http://www.puertos.es/es-es/oceanografia/Paginas/portus.aspx) that provides annual reports and real time data from the Spanish tide gauges. Previous databases report data in absolute values that must be corrected taking into account the local/regional values of subsidence and uplift.</p>

230

231 The methodology proposed by EUROSION (2004) and modified by Benassai et al. (2015) and Di Paola
232 et al. (2018), was employed to select municipalities for study, i.e. the concept of Radius of Influence
233 of Coastal Erosion (RICE). The RICE concept is a proxy for land areas potentially affected by coastal
234 erosion and flooding over a 100-year period, which includes the terrestrial coastal strip located within
235 500 m from the shoreline and/or the areas < 5 m above sea level (EUROSION, 2004). The most

236 populated and tourism-dominated municipalities were examined (Figure 1), i.e. Estepona, Marbella,
237 Fuengirola, Benalmádena, Torremolinos, Málaga and Vélez-Málaga.

238 For the RICE area, the concept of RICE resident population (P_{RICE}), proposed by Benassai et al. (2015),
239 was applied and calculated using the following formula:

240

$$P_{RICE} = D_U * A_{URICE} + D_R * A_{RRICE} + D_N * A_{NRICE} \quad (2)$$

241 where A_{URICE} , A_{RRICE} , and A_{NRICE} indicate the urban, rural, and natural area in RICE, while D_U , D_R , and D_N
242 are the population density for urbanized, rural, and natural areas. Urban, rural, and natural areas
243 were assessed using the CORINE Land Cover (CLC) (Corine Land Cover, 2018), while population
244 densities for each area were obtained using the following equations:

$$D_U = 0.7485 * \frac{Pop}{A_U} \quad (3)$$

$$D_R = 0.217 * \frac{Pop}{A_R} \quad (4)$$

$$D_N = 0.035 * \frac{Pop}{A_N} \quad (5)$$

245 in which A_U , A_R and A_N represent the urbanized, rural and natural areas, respectively, and Pop is the
246 population of each municipality, extracted from the IECA dataset (Fichas municipales. Provincia de
247 Málaga.

248 <https://www.juntadeandalucia.es/institutodeestadisticaycartografia/sima/provincia.htm?prov=29>
249 accessed 29 December 2021).

250 All coastal municipalities in Málaga province (Fig.1) were classified according to the above
251 procedure.

252

253 3.4. State Change

254 Modified by Elliot et al. (2006) from ‘State’ to ‘State change’, describe changes in the natural
255 environmental system as a result of a single or multiple pressures, i.e. changes in coastal dynamics
256 and changes to the health of all levels of biological organization. Changes in the state have impacts
257 on the system.

258 Like the other elements of the chain, the selected indicators were identified from a cause-effect
259 analysis. They were “Loss of dune surfaces” and “Loss of dune vegetation”, “Fragmentation of the
260 dune toe”, “Beach erosion” and “Coastal dynamics changes”, “Flooding” and “Reduction of
261 sediment supply to beaches/coast” and the methodology used to obtain each of them is
262 summarized in Table 2.

263 Table 2. Synthesis of the methodology used to obtain the State Change indicators used in this work.

Type	Indicator	Methodology
State Change	“Loss of dune surfaces” and “Loss of dune vegetation”	To quantify the loss/increment of dune surfaces, the total surface of dune systems at each locality was calculated from Molina et al. (2020a), differentiating: <ul style="list-style-type: none"> - Embryo and mobile dunes - Grass fixed dunes - Stabilized dunes
	“Fragmentation of the dune toe”	Fragmentation of the dune toe, was assessed using the F index calculated by Molina et al. (2020a): $F = l/L \quad (1)$ <p>Where <i>l</i> represents the length of the breaks in the shorefront dune toe and <i>L</i> is the total length of the dune toe. The F Index proposed by Molina et al. (2020a) was not calculated for those systems that disappeared in order to avoid misinterpretation, e.g. the entire disappearance of a dune system is reflected by a decrease in the value of dune toe fragmentation. Values were classified from Class 1 (“Null or very low fragmentation”, $0.00 < F < 0.06$), Class 2 (“Medium fragmentation”, $0.06 < F < 0.16$) to Class 3 (“High fragmentation”, $0.16 < F < 0.41$).</p> <p>The F index at each locality was calculated for each period studied.</p>
	“Beach erosion” and “Coastal dynamics changes”	Shoreline change rates were obtained from Molina et al. (2019a) and divided into different classes based on the statistical analysis of the Weighted Linear Regression (WLR) data for the Mediterranean coast of Andalusia, considering that 50% of the total data corresponded to “Moderate accretion” ($\geq +0.2$; $< +0.5$ m/year) and “Moderate erosion” (> -0.5 ; ≤ -0.2 m/year) classes, values up to the 95% of the total data corresponded to “High accretion” ($\geq +0.5$; $< +1.5$ m/year) and “High erosion” (> -1.5 ; ≤ -0.5 m/year) and values >95% corresponded to “Very high accretion” ($\geq +1.5$ m/year) and “Very high erosion” (≤ -1.5 m/year), and the ± 0.2 interval was considered as “Stability” class.
	“Flooding” and “Reduction of sediment supply to beaches/sea”	Derived via bibliographic review.

264

265

3.5. Impacts (I(W))

266

Modified by Langmead et al. (2007), Cooper (2013, 2012) and O’Higgins et al. (2014) from ‘Impact’

267

to ‘Human impact’ or ‘Welfare’, this parameter reflects the change in human welfare attributable

268

to the state changes. These Impacts in turn elicit a response from society.

269 Indicators selected were “Damage to structures and private property”, “Loss of heritage value”,
270 “Loss of scenery value”, “Loss of tourism attractive”, “Potential loss of jobs in tourism sector”,
271 “Increase of the maintenance costs”, and “Decrease safety of bathers”.

272 As the object of this paper is to test the suitability of the DAPSI(W)R(M) approach to characterize
273 environmental issues, the evaluation of the impact indicators has been carried out via a
274 bibliographic review according to the cause-effect relationships and not according to the specific
275 value of each one of the impacts considered.

276

277 3.6. Responses (R(M))

278 This component was changed to Responses as Management Measures following Smyth et al. (2015)
279 based on a regulatory perspective within the coastal and marine management framework.
280 Responses (as Management Measures) refer to management mechanisms dependent on a
281 governance background, related to policies, politics, administration and legislation (Boyes and
282 Elliott, 2015, 2014) to prevent, compensate, ameliorate or adapt to changes in the state of the
283 environment.

284

285 4. Results

286

287 In this section, indicators selected using the DAPSI(W)R(M) framework are briefly described. As
288 stated before, this paper focuses on the suitability of the method to select the most suitable
289 indicators to describe an environmental issue, not on the application of the method.

290

291 4.1. Driving forces or Drivers (D)

292

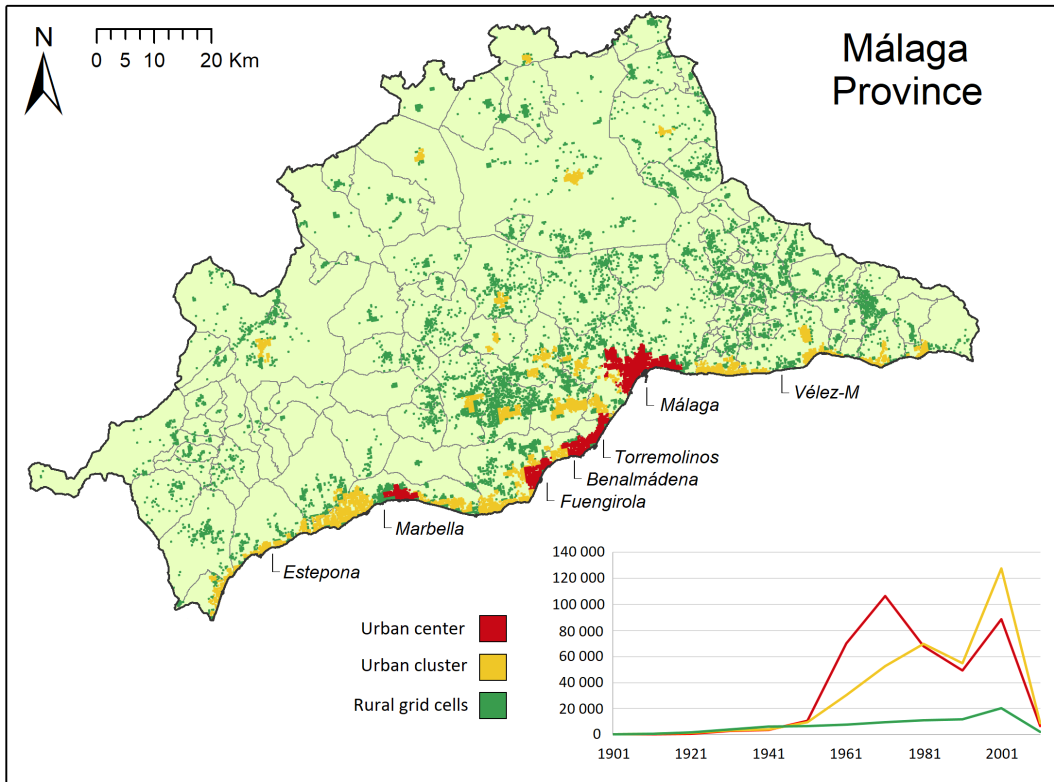
293 As this work is focused on coastal erosion and its relationship with the environment and social
294 systems in touristic areas, the selected drivers were chosen depending on the human activities that
295 affect this issue. Land use and human activities are the human factors that most influence coastal
296 erosion, and these derive from the need for increase or growth (e.g. in urbanization, agriculture and
297 industrialization expansion) and tourism and recreation demands, so these two needs were chosen.

298

299 4.2. Activities (A)

300 Activities selected were urban and tourism development because they promote an increase of
301 physical occupation and activities in the coastal zone.

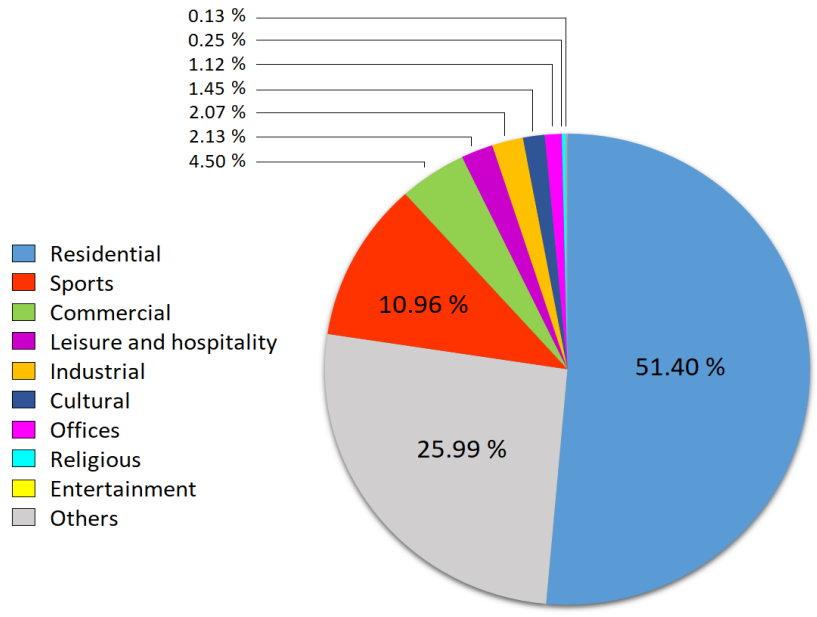
302 Alongside important coastal development, the population of Málaga province increased by ca. 700
303 000 between 1980 and 2021, with a “YoY” growth rate of 0.58% in 2021 (IECA, Junta de Andalucía.
304 <https://www.juntadeandalucia.es/institutodeestadisticaycartografia>, accessed on March 2022).
305 Urban centers and urban clusters are concentrated on the coast and have greatly increased since
306 the 1960s (Figure 6).



307

308 Figure 6. Distribution of urbanized cells classified by settlement size threshold (Eurostat), i.e. urban
 309 center ($\geq 50,000$ inhabitants), urban cluster (5000- 50,000 inhabitants) and rural grid cells (500-
 310 5000 inhabitants). The graph shows the number of houses built per year of the three typologies
 311 from 1901 to 2011 in Málaga province. Data were obtained from *Instituto de Estadística y*
 312 *Cartografía* (IECA, accessed on March 2022).

313 In 2019, the area occupied by buildings was 204,533,631 m², of which 149,318,254 m² are in coastal
 314 municipalities. About half of this area is residential and 20% is used for leisure activities, (Figure 7).



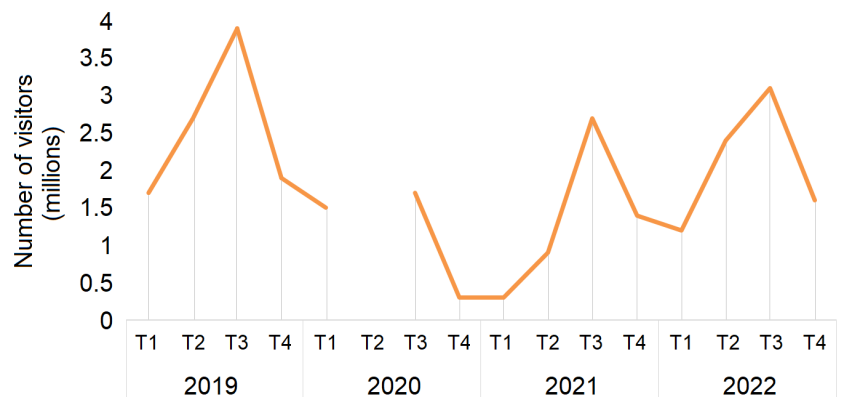
315

316 Figure 7. Surfaces expressed in percentages of the different uses of buildings in 2019 (based on data
 317 of IECA (IECA, accessed in March 2022)).

318 Costa del Sol is internationally renowned for tourism (Malvárez, 2012). In 2019, there were 41,931
 319 regulated tourist establishments (+32.4% compared to 2018) and 396,080 tourist beds (+17.5%
 320 compared to 2018). A +7.1% growth rate of travelers in regulated accommodation was recorded,
 321 more than double the average for Spain (+3.1%). The estimated number of tourists exceeded 13
 322 million people (Diputación Provincial de Málaga, 2020).

323 During the COVID-19 pandemic, tourism dropped considerably and, although an extraordinary
 324 recovery was recorded in 2021, it is still below the record figures of 2019. In 2021 there were 50,837
 325 regulated tourist establishments and 450,081 tourist beds, but the number of estimated tourists
 326 was just over 9 million, 4 million fewer than 2019 (Diputación Provincial de Málaga, 2021).

327 Although tourist activity in Málaga Province is high throughout the year, seasonally peaks are
 328 registered during spring and summer (Figure 8).



329

330 Figure 8. Number of visitors per trimester in Málaga Province, based on the data of IECA (IECA,
331 accessed on May 2023).

332

333 4.3. Pressures (P)

334 The indicators used to quantify pressures in this paper include (Figure 3), as EnMP, “Land use for
335 construction”, “Land use for economic/recreational activities”, “Implementation of coastal
336 protection structures”, “Beach nourishment”, “River basin regulation” and, as ExUP, “Storm
337 damage” and “Sea Level Rise”.

338

339 4.3.1. *“Land use for construction” and “Land use for economic/recreational 340 activities”*

341 Rankings of the municipalities according to the total number of inhabitants and inhabitants of the
342 RICE area do not coincide (Table 3). Also, there are three municipalities with more than 20,000
343 inhabitants in the RICE area, with a clear difference between Málaga and the rest of the
344 municipalities.

345 Table 3. List of the Málaga province municipalities classified according to P_{RICE} ranking. Those
346 selected for the DAPSI(W)R(M) analysis are in bold.

Málaga Province Localities	TOTAL Inhabitants	P _{RICE} Inhabitants
1. Málaga	578,460	96,675
2. Fuengirola	82,837	23,472
3. Marbella	147,633	22,671
4. Vélez-Málaga	82,365	16,172
5. Estepona	70,228	15,095
6. Torremolinos	69,166	14,566
7. Benalmádena	69,144	11,544
8. Rincón de la Victoria	48,768	8,226
9. Mijas	85,397	7,184
10. Nerja	21,144	5,970
11. Torrox	17,943	5,446
12. Manilva	16,439	3,368
12. Algarrobo	6,556	1,898
13. Casares	6,883	408

347

348 The parameters U_{RICE} and E_{RICE} (Table 4) demonstrate strong anthropic alteration of the area by 2006,
349 with an increasing trend until 2018. Tourist and commercial business represents an important sector

350 of the economy of the area, especially for the municipality of Málaga (51.81%), where half of the
 351 urbanized area comprises economic and/or tourist activities.

352

353 4.3.2. *“Implementation of coastal protection structures”*

354 The extent of coastal protection structures in the study area is shown in Table 4.

355 Table 4. Urbanized/industrialized index (U_{RICE}) and land use for economic/recreational activities
 356 (E_{RICE}) for each locality in the RICE area, and armoured coastline expressed in km per year
 357 (Manno et al., 2016, data was updated using 2019 orthophotographs).

Municipality	U_{RICE} 2006		U_{RICE} 2018		E_{RICE} 2006		E_{RICE} 2018		Armouring	
	km ²	%	km ²	%	km ²	%	km ²	%	1956	2019
Estepona	16.53	67.4	18.32	74.8	8.52	51.54	9.49	51.81	2.2	5.9
Marbella	3.65	98.3	3.65	98.3	0.20	5.42	0.21	5.82	1.2	12.7
Fuengirola	12.17	91.3	12.31	92.5	1.31	10.73	1.33	10.78	0	5.2
Benalmádena	3.84	36.9	4.29	41.2	0.31	8.13	0.36	8.48	0	3.7
Torremolinos	8.27	75.7	8.52	78.2	0.66	9.02	0.75	7.70	-	6.4
Málaga	2.61	87.3	2.82	94.7	0.33	12.82	12.3	13.37	7.7	21.7
Vélez-Málaga	4.09	97.3	4.19	99.9	0.62	15.25	0.66	15.66	0	5.6

358

359 Given that the implementation of hard coastal protection structures can be considered as a
 360 measure, it should be clarified that in this work pre-existing coastal structures are considered as
 361 pressures, since they are the main management response to erosion in Andalusia (Manno et al.,
 362 2016; Molina et al., 2019a).

363 As shown in Table 4, the number of structures in Málaga Province coast has varied over time.
 364 Structures observed in the 2019 orthophotos included 59 groins, 51 seawalls/revetments, 14
 365 detached breakwaters, and 11 ports and marinas.

366 4.3.3. *“Beach nourishment” and “River basin regulation”*

367 *“Beach nourishment”*

368 Similar to the implementation of hard coastal protection structures, beach nourishment can be
 369 considered a response to coastal erosion. In this study beach nourishment works carried out in the
 370 past are considered as a pressure that exerts a change in the state of the environment. Beach
 371 nourishment involves the placement of large quantities of borrow sand to create a new beach or
 372 augment an existing one (Dean et al., 2013). The success of beach nourishment (longevity and
 373 economic viability) is very specific and is controlled by local hydrodynamics (Manno et al., 2016;
 374 Pranzini et al., 2018). Regular re-nourishment is necessary to maintain the beaches and stabilize the
 375 shoreline. Although little site-specific information is available on the practice, some examples are:

- 376 - In Málaga, between 1985 and 1988, 135,000 m³ of sand were added to a 1.8 km-long beach
- 377 (Ministerio de Obras Públicas y Urbanismo, 1987).
- 378 - In Estepona, between 1986 and 1987, the beach was nourished with 196,000 m³ of sand
- 379 (Ministerio de Obras Públicas y Urbanismo, 1987).
- 380 - In 1992, approximately 7 million m³ of sediments were artificially injected along 27 km of
- 381 beaches along the Costa del Sol (Gracia et al., 2013; Malvárez García et al., 2000).

382 *“River basin regulation”*

383 River regulation and storage systems have increased in line with the development of urban and

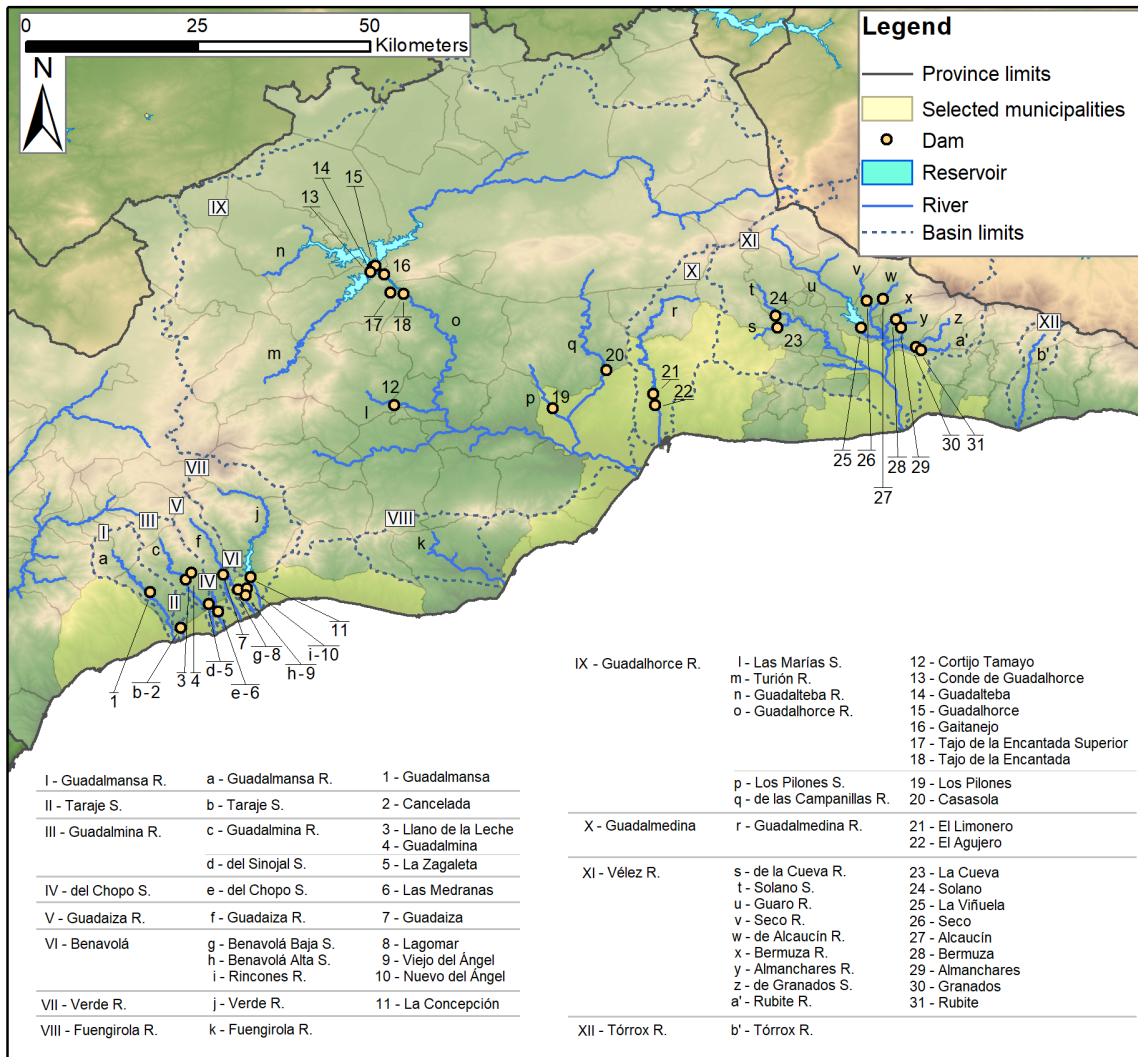
384 agricultural areas.

385 In the Mediterranean side of Andalusia, half of the 26 river basins that have deltas at their mouths

386 are regulated by dams (Liquete et al., 2005). In Málaga province, 31 dams are present (Figure 7)

387 (SNCZI Inventario de Presas y Embalses, Ministerio para la Transición Ecológica y el Reto

388 Demográfico, <https://sig.mapama.gov.es/snczi/> accessed on March 2022).



390 Figure 9. Location of the main rivers and streams of Málaga province and dams inventoried by the
 391 Ministerio para la Transición Ecológica y el Reto Demográfico (SNCZI,
 392 <https://sig.mapama.gob.es/snczi/> accessed, March 2022).

393 Ten of the 12 main river basins that drain the Málaga province are regulated by dams, especially the
 394 Guadalhorce and Vélez river basins with 9 dams each (Figure 9).

395 The largest catchment is the Guadalhorce river basin (3 177 km²). It contains three of the most
 396 important reservoirs whose main function is to supply water for urban and agricultural use, reduce
 397 flood risk, produce energy and permit recreation (Egüen et al., 2015).

398 One of the most important fluvial engineering works in Málaga province is La Concepción dam in
 399 the Verde River basin (Del Río et al., 2015) to which nearby reservoirs, and undammed rivers, were
 400 connected. This river was formerly the main source of sediment to the Marbella coastal area (Del
 401 Río et al., 2015).

402 4.3.4. “Storm damage” as an effect of climate change and “Sea Level Rise”

403 The following indicators, which produce a change in the state of the environment, are considered
 404 here as ExUP because they constitute natural hazards enhanced by climate change processes linked
 405 to Greenhouse gas emissions due to human activities (Gari et al., 2015).

406 “Storm damage”

407 Wave energy flux distribution along the coast associated with very energetic conditions is
 408 considered a good indicator of potential storm damage, as it is the result of a wave propagation
 409 process and therefore reflects several cumulative factors that determine the way in which wave
 410 energy is distributed along the coast (Molina et al., 2020b). Storm wave energy and mean values of
 411 storm wave energy (Molina et al., 2020b) were calculated and classified (Table 5), ranging from very
 412 low to medium classes, with the highest values located in the easternmost areas of the province.

413 Table 5. Mean value of the Energy Flux and related storm class in brackets (from 1 – Very low to 5 –
 414 Very High) at each municipality associated with the two main storm approaching directions (Molina
 415 et al., 2020b).

Municipalities	Energy Flux (kw/m)	
	WSW	ENE
Estepona	5.16 (1)	0.60 (1)
Marbella	9.40 (2)	1.57 (1)
Fuengirola	2.99 (1)	24.10 (3)
Benalmádena	6.61 (1)	23.27 (3)
Torremolinos	2.94 (1)	25.62 (3)
Málaga	5.75 (1)	16.18 (3)
Vélez – Málaga	11.33 (2)	16.50 (3)

417 “Sea Level Rise”

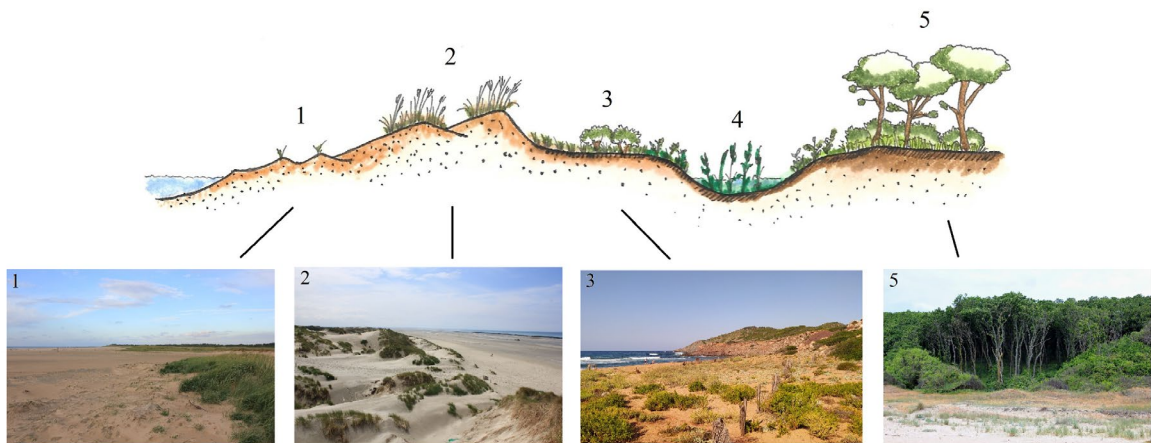
418 Sea-level rise is one of the most important consequences of climate change for coastal communities,
419 and an integrated approach to its damages is essential for the identification of response strategies
420 (Antonioli et al., 2020). In the study area, sea level from 1992 to 2017 shows a positive trend of 2.31
421 ± 0.51 mm/yr (Puertos del Estado, 2019). The IPCC Fifth Assessment Report (Stocker et al., 2013),
422 projected global mean sea level (GMSL) rises in Europe range from 0.36 to 0.63 meters for RCP4.5
423 scenario and from 0.48 to 0.82 for RCP8.5 scenario (Barros et al., 2014). Losada et al. (2014),
424 estimated increments of 0.4–0.45 and 0.6–0.65 meters for the study area for the same scenarios.

425 4.4. State change (S)

426 4.4.1. “Loss of dune surfaces”, “Loss of dune vegetation” and “Fragmentation of
427 the dune toe”

428 These three factors were chosen as indicators since they describe the state of health of the dune
429 systems and also determine their vulnerability to erosive agents.

430 In order to obtain the percentages of the loss/increment of dune surfaces, the total surface of dune
431 systems was calculated at each locality (Table 6) (Molina et al., 2020a). The three classes
432 investigated by previous authors represent the different types of dunes, i.e. Embryo and mobile
433 dunes (Class I), Grass-fixed dunes (Class II) and Stabilized dunes (Class III) (Figure 10).



434

435 Figure 10. Transect of the typical succession of Mediterranean dune typology and vegetation based
436 on Costa (1987). Examples from different areas of: 1, Embryo dunes (photo: Platier d’Oye in Côte
437 d’Opale, France); 2, Mobile dunes (photo: Marquenterre in Côte Picarde, France); 3, Grass fixed
438 dunes (photo: Cala del Pilar in Menorca, Spain); 4, Interdunal depressions; and 5, Stabilized dunes
439 (photo: Lipite in Bulgaria). Photos by A. Mooser.

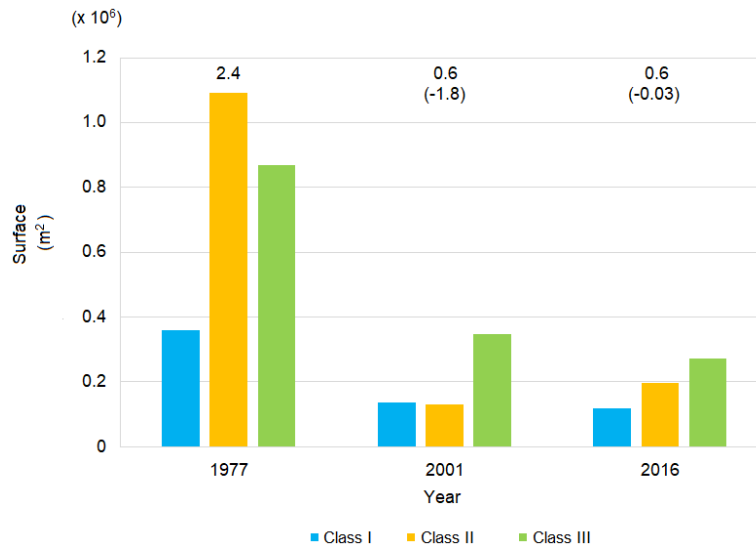
440 Table 6. Balance of the surface area of the total of dunes and dune classes at each locality expressed
441 as percentages with respect to the previous temporal measurement. Fuengirola and Benalmádena
442 lack dune systems, and those in Torremolinos and Vélez-Málaga disappeared in the 1977-2001
443 period.

Localities		1977 – 2001 (%)	2001 – 2016 (%)	1977 – 2016 (%)
Estepona	Class I	-54.98	-52.34	-78.54
	Class II	-63.49	-16.10	-69.37
	Class III	-75.79	8.06	-73.83
	Total	-63.49	-26.90	-73.31
Marbella	Class I	-47.34	19.81	-36.91
	Class II	-87.85	83.92	-77.66
	Class III	-52.72	-21.12	-62.71
	Total	-68.59	2.69	-67.74
Fuengirola	Total	-	-	-
Benalmádena	Total	-	-	-
Torremolinos	Total	-100	-	-100
Málaga	Class I	-54.97	-33.55	-70.07
	Class II	-93.52	16.83	-92.43
	Class III	-87.36	-41.86	-92.65
	Total	-83.43	-24.59	-87.51
Vélez – Málaga	Total	-100	-	-100

444

445 During the 1977 – 2016 period, all dune systems recorded a reduction in surface area (Table 6),
446 however, the process was not constant over time. All dune systems recorded a large reduction in
447 surface area in the 1977 – 2001 period, and in Torremolinos and Vélez-Málaga areas dunes were
448 destroyed by urban development before the Coastal Law of 1988 that regulated the construction of
449 buildings and tourist resorts.

450 The loss (or increase) of dune vegetation, is linked to dune typology. Each typology presents specific
451 vegetation types and each class represents a clear evolution state from embryo and mobile dunes
452 (Class I) to Stabilized dunes (Class III) (Hesp, 2002; Molina et al., 2020a). The 1977–2016 increment
453 in Stabilized dunes (Class III) (Figure 11) was due to the progressive evolution of Grass-fixed dunes
454 (Class II), a natural process. All dunes, however, showed a decrease in all classes in 1977 – 2001 due
455 to human development activities that were not regulated until 1988. In Málaga Province, 1,766,711
456 m² was lost, of which ca. 1 x 10⁶ m² were Class II dunes and ca. 600,000 m² were Class III dunes
457 (Molina et al., 2020a). In the 2001–2016 period, an increase in Class II was linked to the degradation
458 of Class III dunes, through urban development (Gómez Zotano, 2014). This general behavior was
459 observed in Marbella and Málaga municipalities and an increase in Class III due to the stabilization
460 of Class II dunes was observed in Estepona (Table 6).



461

462 Figure 11. Surface area of different dune' classes (modified from Molina et al., 2020b), i.e., "Embryo
 463 and mobile dunes" (Class I), "Grass-fixed dunes" (Class II) and "Stabilized dunes" (Class III). The
 464 values for each year represent the sum of dune surfaces (in million m²) and in brackets the value of
 465 lost dune surface with respect to the time period.

466 The loss of dune surface was linked to the progressive fragmentation of the dune toe (i.e., the
 467 increase of dune discontinuity), which is a useful factor in estimating dune vulnerability (Rangel-
 468 Buitrago and Anfuso, 2015; Rizzo et al., 2018) since a fragmented dune system is more vulnerable
 469 to temporary flooding and, therefore, is less effective against storm surges (Rangel-Buitrago and
 470 Anfuso, 2015; Rizzo et al., 2018). In almost all sectors, fragmentation of the dune toe was due to the
 471 opening of footpaths and their progressive expansion by marine- and wind-induced erosion
 472 processes (Molina et al., 2020a). Table 7 shows values of dune toe fragmentation at each
 473 municipality. Despite their fragmentation has been increasing since 1977, actually only Estepona,
 474 Marbella and Málaga preserve their dune systems.

475

476 Table 7. Values of F index (related class in brackets) and increase/decrease of the fragmentation
 477 value of the dune toe calculated by means of the F index.

Municipality	1977	2001	2016	1977-2001	2001-2016	1977-2016
Estepona	0.04 (1)	0.06 (1)	0.13 (2)	+0.02	+0.07	+0.09
Marbella	0.04 (1)	0.15 (2)	0.17 (3)	+0.11	+0.02	+0.13
Fuengirola	-	-	-	-	-	-
Benalmádena	-	-	-	-	-	-
Torremolinos	*	*	*	*	*	*
Málaga	0.10 (2)	0.09 (2)	0.09 (2)	-0.01	0.00	-0.01
Vélez-Málaga	*	*	*	*	*	*

478

*: F index was not calculated in Torremolinos and Vélez-Málaga since their dune systems disappeared in
 479 the 2001-2016 period.

480

481 4.4.2. "Beach erosion" and "Changes in coastal dynamics"

482 The study area has numerous coastal protection structures, some of which have been modified in
 483 recent decades, i.e. groins were replaced by breakwaters (Manno et al., 2016). These, together with
 484 artificial beach nourishment, altered the natural dynamics of the area and caused shoreline changes
 485 (Manno et al., 2016; Molina et al., 2019a) (Table 8). Accretion and stability occur as a result of the
 486 emplacement of coastal structures and nourishment works, and was recorded at Fuengirola,
 487 Torremolinos and Vélez-Málaga, while erosion was observed at deltas and river mouths.

488 Table 8. Percentages of evolution classes obtained from Molina et al. (2019) for the 1956-2016
 489 period and the most frequent class (in bold) at each locality and Comparison of the percentages of
 490 evolution classes at each locality in 1977-2001 and 2001-2016 periods. The most frequent class at
 491 each locality is marked in bold.

Localities	1956-2016		1977-2001		2001-2016	
Estepona	Accretion	11.4	Accretion	23.8	Accretion	16.2
	Stability	47.0	Stability	60.5	Stability	25.1
	Erosion	41.6	Erosion	15.7	Erosion	58.7
Marbella	Accretion	11.1	Accretion	36.2	Accretion	32.4
	Stability	25.5	Stability	27.1	Stability	39.9
	Erosion	63.4	Erosion	36.6	Erosion	28.3
Fuengirola	Accretion	33.0	Accretion	46.5	Accretion	45.2
	Stability	43.3	Stability	27.7	Stability	31.8
	Erosion	23.7	Erosion	25.8	Erosion	22.9
Benalmádena	Accretion	36.1	Accretion	31.9	Accretion	60.5
	Stability	55.0	Stability	31.9	Stability	30.8
	Erosion	8.9	Erosion	36.3	Erosion	8.7
Torremolinos	Accretion	64.0	Accretion	69.2	Accretion	48.6
	Stability	27.1	Stability	17.8	Stability	11.7
	Erosion	8.9	Erosion	13.0	Erosion	39.7
Málaga	Accretion	39.4	Accretion	45.9	Accretion	42.7
	Stability	17.9	Stability	16.1	Stability	25.2
	Erosion	42.7	Erosion	38.0	Erosion	32.0
Vélez-Málaga	Accretion	48.1	Accretion	57.3	Accretion	62.2
	Stability	19.0	Stability	15.1	Stability	14.2
	Erosion	32.9	Erosion	27.5	Erosion	23.7

492

493 Comparison of the evolution rates in the two studied periods, i.e., 1977-2001 and 2001-2016,
 494 generally shows no major change (Table 8). Only three municipalities did exhibit marked changes:
 495 (1) Estepona, with a large increase in erosion and decrease in stability; (2) Marbella, which showed

496 an increment in stability at the expense of erosion; and (3) Benalmádena, with an important increase
497 in accretion and decrease in erosion.

498

499 4.4.3. “Flooding” and “Reduction of sediment supply to beach/sea”

500 “Flooding”

501 Flooding is one of the main natural hazards threatening environmental resources, human lives and
502 structures (Ciampa et al., 2021; European Commission, 2018). Coastal flooding is increasingly
503 common in many coastal areas and is expected to become more frequent and severe as sea-level
504 rises (Hino et al., 2019; Moore and Obradovich, 2020).

505 Besides climate change forcing, intensive urbanization increases flood hazard plus environmental
506 degradation, as the degree of inundation and associated disturbance depend on local topography
507 and the distribution of infrastructure, housing and economic activity (Moore and Obradovich, 2020).
508 One of the main socio-economic impacts of climate change is expected to be coastal floods (Diaz,
509 2015; Hallegate et al., 2013).

510 In order to properly respond to coastal flooding events, is necessary to understand where floods
511 can occur, conditions that produce them and the consequences for communities and infrastructure
512 (Hallegate et al., 2013). The extent of flooding varies even within a small area depending on local
513 topography (Strauss et al., 2012). The social impacts depend on the distribution and characteristics
514 of infrastructure, housing and economic activities. Some projects about flood hazard and associated
515 risk in Spain are outlined below:

516 - According to the European Directive 2007/60/EC on the assessment and management of
517 flood risks, Spain developed a specific program on flood hazards
518 (<https://www.miteco.gob.es/es/agua/temas/gestion-de-los-riesgos-de-inundacion/>,
519 accessed, May 2023);

520 - A project on coastal flooding in Spain was developed by Gil-Guirado et al. (2019) for the
521 Spanish Mediterranean region. The resulting *Spanish Mediterranean Coastal Flood* (SMC-
522 Flood) database identifies Málaga as the most threatened area, due to the intensity and
523 frequency of flood events (Gil-Guirado et al., 2019);

524 - At regional level, the regional administration (i.e. Junta de Andalucía) developed a project
525 about the assessment of the risk of marine floods associated with sea level rise on the
526 Andalusian coast. Methodological results were published by (Ojeda-Zújar et al., 2021) and a
527 Web Map Service (WMS) is available online at the REDIAM web portal
528 ([https://portalrediam.cica.es/geonetwork/srv/api/records/2acaa60e-cf3c-4570-90f4-
529 3d2cf8b57866](https://portalrediam.cica.es/geonetwork/srv/api/records/2acaa60e-cf3c-4570-90f4-3d2cf8b57866), accessed, May 2023). Ports and fluvial plains presented the highest values
530 of risk.

531 “Reduction of sediment supply to the beach”

532 Sediment supply to the beach-dune system is related to nearshore currents and rivers. Variations in
533 supply can be due to natural changes in wave climate and current pathways (Orford et al., 2002;
534 Shand et al., 2001), or coastal structures that interrupt longshore transport (Manno et al., 2016;
535 Pranzini et al., 2020). Variations in rainfall, changes in land use (e.g., soil erosion increases when
536 forests and grasslands are converted into pastures and farm fields) and the construction of dams
537 and the channelization of river courses are the main causes of reduction of fluvial sediment supply.
538 31 dams are present in Málaga province (Figure 9).

539 River deltas are most affected by the reduction of sediment supply (Syvitski, 2008). Such sediment
540 decrease has led to a decrease in subaerial delta area and affected the rates of subsidence,
541 producing landward shoreline displacement (Besset et al., 2019).

542 The Vélez river delta experienced erosion rates of 3.5 and 4.8 m/year between 1956–1979 and
543 1979–2009, respectively (Prieto et al., 2012). Severe alterations of the sediment budget are linked
544 to the Verde River regulation because of the construction of La Concepción dam and, secondarily,
545 to the massive coastal land occupation and the emplacement of numerous coastal protection
546 structures and associated down-drift erosion processes (Del Río et al., 2015; Del Río and Malvárez,
547 2016).

548 4.5. Impacts (I(W))

549 Within the DAPSI(W)R(M) framework, indicators of impacts should express changes in human
550 welfare caused by alterations in the environmental state (Figure 2). As previously stated, the impact
551 indicators have been selected based on cause-effect relationships based on a bibliographic review
552 and their value has not been evaluated, since the objective of this work is not the implementation
553 of the method but the evaluation of its effectiveness. With the focus on coastal touristic areas,
554 indicators related to tourism were selected (Figure 4), and brief description/examples are listed
555 below:

556 - Safety impacts

557 Beach erosion and flooding are the most important threats to structures and private property.
558 As an example, a winter storm in April 2022 produced damage to structures and private property
559 documented by newspapers (La Opinión de Málaga,
560 <https://www.laopiniondemalaga.es/malaga/2022/04/05/temporal-levante-numerosos-danos-costa-sol-occidental-64671798.html>,
561 accessed, June 2022; Canal Sur,
562 <https://www.canalsur.es/noticias/andaluc%C3%ADa/malaga/preocupacion-en-el-litoral-andaluz-por-los-danos-del-temporal-a-las-puertas-de-la-semana-santa/1817580.html>
563 accessed, June 2022). Similar damage has also occurred on other occasions (Figure 12).
564



565

566 Figure 12. A and B, damage on the promenade and ‘chiringuitos’ in Baños del Carmen, El Pedregalejo
 567 Beach (Málaga) documented by newspapers (Zea et al., 2022), and C and D damage to facilities
 568 caused by 2017-2018 winter storms in Torremolinos: waves break directly on the shower and
 569 ‘chiringuito’ (C) and the sand has reached the promenade covering the paths and water-drinking
 570 fountains (D) (Dirección General de Sostenibilidad de la Costa y el Mar, 2018).

571 Regarding the safety of beach users, changes in beach morphology and/or dynamics (due to
 572 nourishment works or the emplacement of protection structures) could increase rip currents
 573 that pose an important risk for bathers as they increase the risk of drowning (Rojas et al., 2014;
 574 Semeoshenkova et al., 2017). As an example, in Spain, 217 people drowned in 2022 according
 575 to the Royal Spanish Federation of Rescue and First Aid ([https://rfess.es/2023/01/casi-400-](https://rfess.es/2023/01/casi-400-muertes-por-ahogamiento-en-2022/#.ZGNrsXZByUk)
 576 [muertes-por-ahogamiento-en-2022/#.ZGNrsXZByUk](https://rfess.es/2023/01/casi-400-muertes-por-ahogamiento-en-2022/#.ZGNrsXZByUk), accessed, May 2023).

577

578 - Social impacts

579 Cultural heritage assets located in coastal areas are also vulnerable to coastal erosion
 580 (Figure 13) but, because of their historical and cultural interest, they are regarded as in
 581 particular need of protection.



582

583 Figure 13. An example of historical heritage destroyed by coastal erosion in Málaga. Torre de la Miel
584 (Nerja, Málaga), a 16th century watchtower whose deterioration due to the impact of storms and
585 coastal erosion was already evident in 1743 according to historical writings (photo provided by
586 Hispania Nostra, accessed, June 2022).

587 Scenery, one of the five most important parameters to coastal visitors (Mooser et al., 2018;
588 Williams, 2011), is negatively influenced by urban development and coastal protection
589 structures (Rangel-Buitrago et al., 2011; Semeoshenkova and Newton, 2015). Examples in
590 Málaga include the degradation of coastal dune systems (Molina et al., 2020a), and
591 transformation of natural coastal landscapes into dense touristic and urban areas (Figure 6).

592 - Economic impacts

593 Regarding economic impacts, the tourism industry dominates the economy of the coastal
594 area. The Mediterranean is the world's leading destination with almost one-third of its
595 income generated by the tourism sector (World Tourism Organization (UNWTO), 2016), and
596 this industry largely depends on the presence of beaches (Botterill et al., 2000; White et al.,
597 2010).

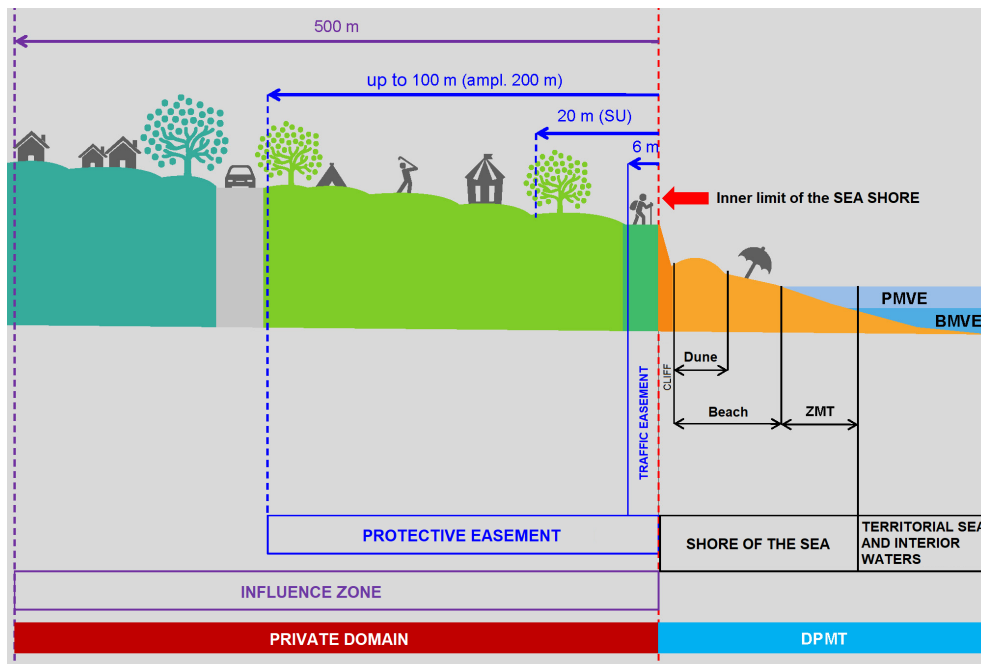
598 Uncontrolled growth of coastal tourism was driven by the desire for maximum economic
599 benefit. This, however degraded coastal scenery with negative impacts in the economic,
600 social and cultural attributes of these areas (Rangel-Buitrago et al., 2019). This reduction in
601 attractiveness of coastal areas could reduce investment, and future revenue in the tourist
602 sector (Semeoshenkova et al., 2017).

603 The increase in the maintenance costs of infrastructure is expected to increase as they are
604 affected by coastal erosion. In Spain, *Dirección General de la Costa y el Mar* (DGCM, the
605 governing body of the Ministry for the Ecological Transition and the Demographic Challenge
606 of the Government of Spain, <https://www.miteco.gob.es/es/costas/temas/default.aspx>) is
607 responsible for such actions in the maritime-terrestrial public domain. The Local
608 Administration, however, has competence in facilities management and in beach and public
609 space cleanliness, hygiene and health maintenance (Spain Government, 2013). It is

610 therefore difficult to quantify the total maintenance costs, but some examples are listed
 611 below in 4.6 Responses (R(M)).

612 4.6. Responses (R(M))

613 The DAPSI(W)R(M) framework helps identify the responses that best fit each of the identified
 614 impacts. As mentioned above, these Responses must be understood from a regulatory perspective
 615 and can form the basis for coastal and marine management. In Spain, responsibility for such
 616 responses lies with central government who manages the coast (the public maritime-terrestrial
 617 domain, DPMT, Figure 14), and the local administrations who manage the area of influence behind
 618 the beach and beyond – where facilities are located. Regional administrations manage protected
 619 natural spaces. The Coastal Act is the highest level regulation in Spain.



620
 621 Figure 14. Synthesized scheme of the limits of the maritime-terrestrial public domain in Spain
 622 modified from the Ministry for the Ecological Transition and the Demographic Challenge
 623 ([https://www.miteco.gob.es/es/costas/temas/proteccion-costa/conociendo-litoral/zonas-](https://www.miteco.gob.es/es/costas/temas/proteccion-costa/conociendo-litoral/zonas-litorales-espanolas/clasificacion-legal/litoral-en-legislacion.aspx)
 624 [litorales-espanolas/clasificacion-legal/litoral-en-legislacion.aspx](https://www.miteco.gob.es/es/costas/temas/proteccion-costa/conociendo-litoral/zonas-litorales-espanolas/clasificacion-legal/litoral-en-legislacion.aspx), accessed, July 2022). DPMT:
 625 public maritime-terrestrial domain; ZMT: maritime-terrestrial zone; PMVE: equinoctial minimum
 626 spring high tide; BMVE: equinoctial maximum spring low tide.

627 Responses to the impacts identified are approached via spatial planning and coastal management
 628 involving the different administrative levels. As an example, some of the plans developed in Spain
 629 are:

- 630 - Strategies for Coastal Protection
 631 (<https://www.miteco.gob.es/es/costas/temas/proteccion-costa/estrategias->

- 632 proteccion-costa/cadiz/estrategia-proteccion-cadiz-malaga-almeria.aspx,
633 accessed, May 2023).
- 634 - Flood risk management plans
635 ([https://www.miteco.gob.es/es/agua/temas/gestion-de-los-riesgos-de-](https://www.miteco.gob.es/es/agua/temas/gestion-de-los-riesgos-de-inundacion/planes-gestion-riesgos-inundacion/)
636 [inundacion/planes-gestion-riesgos-inundacion/](https://www.miteco.gob.es/es/agua/temas/gestion-de-los-riesgos-de-inundacion/planes-gestion-riesgos-inundacion/), accessed, May 2023).
- 637 - Adaptation strategy of the Spanish coast to climate change
638 ([https://www.miteco.gob.es/es/costas/temas/proteccion-](https://www.miteco.gob.es/es/costas/temas/proteccion-costa/estrategiaadaptacionccaprobada_tcm30-420088.pdf)
639 [costa/estrategiaadaptacionccaprobada_tcm30-420088.pdf](https://www.miteco.gob.es/es/costas/temas/proteccion-costa/estrategiaadaptacionccaprobada_tcm30-420088.pdf), accessed, May 2023).
- 640 - Andalusian Strategy Proposal for Integrated Management of Coastal Zones (GIZC)
641 ([https://www.juntadeandalucia.es/medioambiente/portal/web/guest/areas-](https://www.juntadeandalucia.es/medioambiente/portal/web/guest/areas-tematicas/litoral/gestion-integrada-de-zonas-costeras-gizc/estrategia-andaluza-de-gestion-integrada-de-zonas-costeras)
642 [tematicas/litoral/gestion-integrada-de-zonas-costeras-gizc/estrategia-andaluza-](https://www.juntadeandalucia.es/medioambiente/portal/web/guest/areas-tematicas/litoral/gestion-integrada-de-zonas-costeras-gizc/estrategia-andaluza-de-gestion-integrada-de-zonas-costeras)
643 [de-gestion-integrada-de-zonas-costeras](https://www.juntadeandalucia.es/medioambiente/portal/web/guest/areas-tematicas/litoral/gestion-integrada-de-zonas-costeras-gizc/estrategia-andaluza-de-gestion-integrada-de-zonas-costeras), accessed, May 2023).
- 644 - At the local level, Municipalities have beach management plans that can be
645 accessed, e.g. Málaga
646 ([https://playas.malaga.eu/portal/menu/seccion_0002/secciones/subSeccion_000](https://playas.malaga.eu/portal/menu/seccion_0002/secciones/subSeccion_0005)
647 [5](https://playas.malaga.eu/portal/menu/seccion_0002/secciones/subSeccion_0005), accessed on May 2023) or Fuengirola ([https://www.fuengirola.es/wp-](https://www.fuengirola.es/wp-content/uploads/2021/06/Firmado-P.-Calidad.pdf)
648 [content/uploads/2021/06/Firmado-P.-Calidad.pdf](https://www.fuengirola.es/wp-content/uploads/2021/06/Firmado-P.-Calidad.pdf), accessed, May 2023).

649 Examples of engineering approaches examples are very numerous and, in general, derive from
650 spatial planning and coastal management. As an example, storm damage repair works are carried
651 out by the Ministry for the Ecological Transition and the Demographic Challenge of the Government
652 of Spain and its approval is regulated through the “Plan Litoral”
653 ([https://www.miteco.gob.es/es/costas/temas/proteccion-costa/plan-litoral-obras-reparacion-](https://www.miteco.gob.es/es/costas/temas/proteccion-costa/plan-litoral-obras-reparacion-temporales/)
654 [temporales/](https://www.miteco.gob.es/es/costas/temas/proteccion-costa/plan-litoral-obras-reparacion-temporales/)):

- 655 - In 2017, a total of €35,806.45 was invested in repairing damage to the Artola dunes
656 and Las Chapas beach (Marbella) and in 2015, €222,624.28 was invested in repairing
657 the groins on A Poniente beach in Marbella
658 ([https://www.miteco.gob.es/es/costas/temas/proteccion-costa/actuaciones-](https://www.miteco.gob.es/es/costas/temas/proteccion-costa/actuaciones-proteccion-costa/malaga/act-marbella.aspx)
659 [proteccion-costa/malaga/act-marbella.aspx](https://www.miteco.gob.es/es/costas/temas/proteccion-costa/actuaciones-proteccion-costa/malaga/act-marbella.aspx), accessed, May 2023).
- 660 - In 2016, €3,368,064.96 was invested in the remodeling of the Fuengirola
661 promenade ([https://www.miteco.gob.es/es/costas/temas/proteccion-](https://www.miteco.gob.es/es/costas/temas/proteccion-costa/actuaciones-proteccion-costa/malaga/act-fuengirola.aspx)
662 [costa/actuaciones-proteccion-costa/malaga/act-fuengirola.aspx](https://www.miteco.gob.es/es/costas/temas/proteccion-costa/actuaciones-proteccion-costa/malaga/act-fuengirola.aspx), accessed, May
663 2023).

664

665 **5. Discussion: Utility of the DAPSI(W)R(M) approach**

666 Coastal management is a multi-disciplinary, multi-agency activity (McKenna et al., 2009, 2008) that
667 is often unable to achieve its goals (Neal et al., 2018). Application of the DAPSI(W)R(M) framework
668 to characterize the environmental issues of heavily developed coastal tourist areas provides some

669 insights into its utility as an integrative management tool that may help overcome some of these
670 difficulties (Figure 4).

671 In following the DAPSI(W)R(M) approach the manager can benefit from the way the data is
672 presented, in the sense that the cycle form assists the identification of indicators and the
673 relationships between them. Sorting the data in a cyclic scheme helps managers to identify that part
674 of the chain in which impacts occur, how they affect the rest of the cycle, and the possible responses
675 to avoid it, based on an understanding of the linked natural-human system (e.g. Malvárez et al.,
676 2021).

677 In addition, the unifying DAPSI(W)R(M) methodology can facilitate the establishment of response
678 measures to respond to local problems with due recognition of other actions taken in nearby areas
679 at different administrative levels (McKenna et al., 2009). At higher administrative levels, the
680 approach could allow the comparison of problems in different regions or countries, which would
681 allow better management of programs and funds for example, for the protection of coastal areas
682 against erosion processes.

683 Compared with other frameworks such as SESF (Ostrom, 2009, 2007) or SAF (Hopkins et al., 2011),
684 DAPSI(W)R(M) is presented as a more user-friendly, communicative tool that compartmentalizes
685 the social-ecological system in a cause-effect-response chain. The DAPSI(W)R(M) approach should
686 not be understood as a sophisticated social-ecological system framework but rather as a tool that
687 helps to organize complex systems and to identify viable options to manage and protect systems
688 (Lewinson et al., 2016). To achieve this the DAPSI(W)R(M) uses the most relevant indicators to
689 assess an environmental issue.

690 On the other hand, the process can identify data gaps (e.g. regarding beach nourishment in the
691 study area). The identification of such gaps can be useful for researchers and managers to seek
692 additional data or to identify other indicators to fill those gaps.

693 The DPSIR approach for this purpose can be improved by clear definition of each part of the cycle.
694 The definition of driver forces is often confused as any force that produces a pressure in the
695 environment, so that some authors wrongly include "natural drivers". Also, Drivers are often
696 interpreted as activities or sectors and their meaning can also vary depending on the background of
697 the person who interprets them, e.g. natural *versus* social scientists. State changes and Impacts are
698 also often confused in such a way that the same indicator can be found in one or another part of
699 the cycle depending on the interpretation of the author. The application of the DAPSI(W)R(M) helps
700 to clarify these problems, but each author's interpretation continues to include some subjectivity.

701 Regarding stakeholder mapping, the visual process of laying out all the stakeholders on one map
702 (Alamanos et al., 2021; Ioanna et al., 2022), is not an integral part of the process but the results of
703 the DAPSI(W)R(M) analysis could be used to facilitate stakeholder engagement. Following Newton
704 and Elliot (2016), stakeholders can be classified following the DAPSI(W)R(M) approach, facilitating
705 the stakeholder mapping, in "inputters" and "extractors" (those creating the pressures),
706 "regulators" (those who have competency to regulate the area in study, e.g. administrative bodies),
707 "beneficiaries" (those who take advantage of the uses and materials provided by the system, e.g.

708 the society), “affectees” (those who are affected by the use and managing of the area), and
709 “influencers” (those who play a part in directing the nature of the area, e.g. politicians, non-
710 governmental organizations, media, academics, and educators)(Cormier et al., 2019; Elliott et al.,
711 2020).

712 A shortcoming noted by other authors when applying the DAPSI(W)R(M) framework is the
713 requirement of a good definition of the system boundaries, since the definition of what is important
714 for an issue, what has to be included in the evaluation, and what has not, depends on it (Atkins et
715 al., 2011; Svarstad et al., 2008). Certain management measures may be introduced at locations that
716 are remote from the source of a considered pressure or responses can have a different scale to local
717 activity when they address ExUP, including for example, consequences of climate change (Barnard
718 and Elliott, 2015; Elliott, 2014).

719 DAPSI(W)R(M) was designed to assess environmental issues in a social-ecologic system approach.
720 Therefore, if the boundaries of the studied system are extended, the complexity of the cycle will
721 increase. A single DAPSI(W)R(M) cycle can be considered, as has been done in this work, as a
722 mechanism for achieving a better understanding of the system and the relations between the
723 different steps of the cycle, since the initial DPSIR framework was developed to be a communicative
724 tool to simplify and analyze socio-ecological systems (Elliott and O’Higgins, 2020); but it is necessary
725 to know that one activity will impact on others, as illustrated by Elliot et al. (2017) in the ecosystem
726 services approach: a single DAPSI(W)R(M) cycle, discretely bounded for a particular sector or
727 activity, is nested within a set of DAPSI(W)R(M) cycles that comprise many sectors or activities with
728 complex non-linear links and feedback loops between them (Atkins et al., 2011; Elliott et al., 2017).

729 The introduction of intermediate steps or factors as economic sectors grouping specific activities or
730 ecosystem services in the approach is also common in recent studies (Abalansa et al., 2020; García-
731 Onetti et al., 2018; Pouso et al., 2020; Verling et al., 2021). The introduction or omission of these
732 additional factors depend generally on the area of knowledge of the authors and entails more
733 complexity in developing the study, especially for those who are not specialized in the study of
734 ecosystem services.

735 Recent reviews focused on DPSIR and derivatives such as DAPSI(W)R(M) (Gari et al., 2015; Lewinson
736 et al., 2016; Patricio et al., 2016; Smith et al., 2016) highlight the potential utility of the approach
737 for the analysis and management of complex social-ecological systems but also identify the need for
738 caution or due consideration in the use of definitions, as has also been shown in this paper.

739 Despite criticism and limitations (Berger and Hodge, 1998; Gregory et al., 2013; Rapport et al., 1998;
740 Rekolainen et al., 2003), the DAPSI(W)R(M) framework is still in use in assessing environmental
741 issues, and its language, i.e. Drivers, Activities, Pressures, State Change, Impacts and Responses, is
742 used in decisions, directives and many working documents of the European Commission (Verling et
743 al., 2021) and in research studies (e.g. Atkins et al., 2011; El Mahrhad et al., n.d.; Hallett et al., 2016;
744 Lonsdale et al., 2017). According to Lewinson et al. (2016), the incorporation of a numerical
745 representation of relationships between components of the DAPSI(W)R(M) framework could
746 represent a new approach that enhances the utility of the framework not only to identify indicators,

747 also to quantify the height of each indicator for a better assessment of environmental issues in a
748 social-ecological system.

749 The DAPSI(W)R(M) framework is intended to identify, analyze and assess environmental problems
750 and consequences along with the responses needed to rectify the damage done to nature and
751 society (Gari et al., 2015). Notwithstanding some limitations identified in this test application, the
752 DAPSI(W)R(M) approach does indeed appear to offer a useful, integrative tool for strategic
753 management of touristic coastal areas.

754 The application of the DAPSI(W)R(M) approach can improve coastal management in the study
755 locality (and elsewhere) through the development of a simple model that characterizes
756 environmental issues from the causes to the consequences by means of indicators and the
757 relationships between them. The cyclic form of the model permits an easy identification of where
758 the problem is and who is involved with its resolution, helping with stakeholder mapping and
759 decision-making regarding suitable responses. The results can be taken to other administrative
760 levels or other heavily developed tourist coastal areas. With the use of the same model at the local
761 level, compatible or complementary management plans could be developed for adjacent or similar
762 areas, to enable a more effective response to the complex problems that affect them.

763

764 **6. Conclusions**

765 Numerous frameworks have been developed to define environmental issues being the
766 DAPSI(W)R(M) framework one of them: the six categories, i.e. Drivers, Activities, Pressures, State
767 Change, Impacts (on Human Welfare) and Response (as Management measures), are represented
768 by environmental indicators that are connected following a sequence and creating feedback loops.
769 It is a tool that helps the identification of the variety of indicators used to appropriately describe an
770 environmental issue and the relations between human activities and the environment. In this paper,
771 the suitability of the DAPSI(W)R(M) framework to characterize the environmental issues affecting
772 touristic coastal areas was tested. The different components and indicators were assessed by a
773 comprehensive literature review and data obtained in previous works in the Málaga province
774 coastal system, and the DAPSI(W)R(M) method was applied to the coastal municipalities with the
775 highest population density, focusing on the relations between coastal erosion and associated effects
776 on the environment and social systems.

777 The main limitation identified during the development of this paper was confusion in the
778 terminology used. Even though the development of the DAPSI(W)R(M) clarified most of the
779 definitions, some subjectivity remains and much depends on the individual author's interpretation.

780 Although some limitations identified in this test application exist, in general the results indicate that
781 the DAPSI(W)R(M) framework is a good and useful method to characterize the main environmental
782 issues that affect coastal areas. It is an accessible tool for coastal managers and allows a complete
783 vision of human activities and environmental processes within a specific scenario.

784 In the study locality, the application of the DAPSI(W)R(M) approach affords an opportunity to
785 develop a coastal management plan compatible with and/or complementary to management plans
786 of adjacent and similar areas, and to identify effective responses to the problems that affect them,
787 by using the same model (the DAPSI(W)R(M) cycle) to characterize environmental issues from
788 causes to consequences via indicators and the relationships between them.

789

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