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1 Title:

2 The extended concept of Littoral Active Zone considering soft sediment shores as social-ecological
3 systems, and an application to Brittany (North-Western France)

4

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18

19 Abstract:

20 This paper applies and extends the concept of Littoral Active Zone (LAZ) of sandy beaches as a
21 relevant dimension to observe and manage this socio ecological system. The LAZ is a dynamic zone
22 where exchanges across land and sea occur, and this concept was initially proposed on a
23 geomorphological background only. However, to achieve full relevance and timely address
24 management choices tied to the functioning of soft sediment shores, it became appropriate to
25 extend its consideration to both the ecological and social templates co-existing on the same
26 physical unit. Current paradigms around the concept of LAZ were used as a background to
27 organize information from different disciplines and extend the concept to different soft sediment
28 shores (mostly sandy beaches and salt marshes), towards a global, integrated relevance of the
29 concept.

30 As a test for this approach, we 1) structured information on the biophysical and social templates
31 around the concept of LAZ, 2) extended it to salt marshes and 3) applied it to the case of the
32 Breton coast for a practical test on information organization. Such an exercise highlighted key
33 characteristics of the LAZ using a multidisciplinary approach, but also gaps to be filled when

34 targeting research, perception, communication, sustainable use and management of the LAZ as a
35 functional unit.

36

37 **1. Study approach**

38 The background information (paragraphs 2-5) was structured by gathering current paradigms and
39 definitions around soft sediment –when concepts are still debated, versions presented are backed
40 by references and related empirical data. The call for extension of the concept of sandy beach,
41 opening options for landscape scale considerations, is here answered by considering salt marshes
42 (motivations detailed in paragraph 6), hence the use of “soft sediment shores”. Human-modified
43 beaches are included in the background (paragraph 7), assuming that this is a most common
44 condition, in a context where sandy shores are affected by human-driven phenomena –though to
45 a different extent- at global scale. The social template of the Littoral Active Zone is described on
46 such background, and defined physically in space and time to reach the depiction of its boundaries
47 (paragraph 8). We finally provided detailed information for the case of Brittany (paragraph 9),
48 utilizing the standard structure of a social-ecological system as two templates (the social and
49 ecological one), inter-connected by adaptive management and ecosystem services. To this aim,
50 information comprehends not only scientific papers but also grey literature and references to
51 ongoing projects. Conclusions are an open invitation to consider the LAZ and its diverse
52 components as the proper dimension to approach and manage systems connecting land and sea.

53

54 **2. Current paradigms on sandy shores: patterns and processes across the Littoral Active Zone.**

55 Sandy shores are ecotonal systems connecting land and sea. Their definition is slightly different
56 depending on the discipline considered. For instance, in geomorphology the “beach” goes from
57 the depth of closure to the upper limit of the runup under extreme waves, and the dune is
58 excluded from the sandy shore definition *sensu stricto* (Komar, 1989). In ecology, sandy shores
59 consist of three entities along the land-sea axis: surf zones, beaches and dunes. Each one of them
60 is characterized by distinct organism assemblages, tightly related to the physical constraints of the
61 microhabitats they inhabit (McLachlan and Defeo 2017 and references within). A unifying concept
62 is that the different zones along the land-sea *continuum* are connected by a constant exchange of
63 energy and material, including boulders, pebbles, gravel, sand or silt (see Wentworth, 1922 for
64 sediment size categories). Hence the concept of Littoral Active Zone (LAZ) (Tinley, 1985) was
65 proposed to define a soft-sediment coastal system, with boundaries identified by the effects of
66 the waves (seaward) and aeolian (landward) transportation of sediment. Sediment is in fact being

67 exchanged across the geomorphic system of the LAZ, in a dynamic process. This led to the use of
68 sediment budget (Komar, 1989) for sandy shores management purposes: the concept of LAZ
69 referred to the littoral geomorphology and proposed the management of a unit including both
70 marine beach/surf zone and terrestrial dune ecosystems. However, such a conceptual framework
71 has not been fully applied to the biotic component of the system, where multi-level exchanges (of
72 energy, material and nutrients) occur along the same unit (after McLachlan and Defeo, 2017):

- 73 • Primary producers (surf phytoplankton, seagrasses, benthic microflora, pioneer and dune
74 vegetation);
- 75 • Primary consumers (dominated by bacteria, peracaridans, annelids, mollusks, insects);
- 76 • Predators (dominated by birds, coleopterans, spiders, crabs)
- 77 • “Temporary” i.e. only spending within the LAZ a key stage of their life-cycle: planktonic
78 larvae and juvenile stages; nesting or migrating birds; nesting turtles.

79 While research on sandy shores provided a solid background with respect to morphodynamics,
80 current knowledge related to biotic components indicates that they are 1) mostly physically
81 driven and 2) generally known in terms of patterns, but with a gap in knowledge concerning
82 the processes shaping the patterns measured (Defeo and McLachlan 2013).

83

84 **3. Across-shore dimension.**

85 Along the LAZ, at a dimension defined as “mesoscale” in ecology of sandy shores (i.e. “within
86 beaches”), both water-breathing and air-breathing organisms can be found, following zonations
87 which fluctuate in space and time linked to habitat availability (McLachlan and Jaramillo, 1995).
88 Indeed, the beach is the one entity of the LAZ in which both water-breathers and air-breathers co-
89 occur (Defeo and McLachlan, 2005), while surf zones are exclusively inhabited by water-breathers
90 and dunes by air-breathers. Dugan (2013) proposed the concept of “envelopes” for the beach
91 entity, i.e. spatial units affected by temporal units varying daily-to-yearly. This explained
92 macrofaunal patterns better than the mere “beach width” variable. Scapini et al. (2019) remarked
93 on the relevance of behavior in the macrofauna zonation patterns, with plasticity as the main
94 adaptation to recover and maintain a suitable habitat. By extending the analysis to the whole LAZ,
95 the characteristic mobility of substrate is the main biotic driver that shapes microhabitats and to
96 which the fauna adjusts their behavioural responses.

97

98 **4. Along-shore dimension.**

99 Each LAZ across-shore relates to an along-shore unit (perpendicular to the land-sea axis), which
100 can be called the physiographic unit, sedimentary cell, or beach units. Along-shore dimension is
101 defined by natural headlands or man-made structures overpassing the depth of closure, i.e. the
102 depth to which the cross-shore sedimentary exchange is insignificant and which is identified
103 where bathymetric profiles repeated over time are connected (closed) (Hallermaier, 1977). By
104 considering the dune as a part of the Active Zone, units can also overpass headlands (e.g. locations
105 in which transgressive dunes have climbed escarpments and passed the headlands, Pye and Blott,
106 2020). Embayments and pocket beaches, with boundaries generating turbulence and rip currents
107 at their edges, are easy to identify as units. Within units however, as e.g. in the case of extended
108 beaches, exposure and longshore currents may affect the sand mobility (Komar, 1989); hence a
109 beach can hence include a continuum from deposition to erosion, confusing the identification of
110 units along-shore (Carter, 1988). Also mixed conditions such as sparse rocks present on sand
111 substrates, affect the flow of energy and material within units. Dynamics become more relevant in
112 the case of wrack inputs ashore, driving the spatio-temporal patterns of stranding. In ecology,
113 given the large amount of studies focusing on sand-only conditions, conditions of periodical inputs
114 of stranded material are often overlooked. However, they are important in terms of dynamics
115 backing the biotic patterns measured ashore. In general, beach fauna patterns present land-like
116 characteristics (McLachlan and Defeo, 2017 but also see Defeo and McLachlan, 2011), with single
117 beaches (“ecological mesoscale”) remaining an essential unit for analysis.

118
119 In summary, the paradigm of sandy beaches as physically-controlled environments, when applied
120 to the mobility of the substrate as LAZ characteristic, highlights the following features as keys for
121 resident biota:

- 122 1) Pore space for the development of rich interstitial fauna dominated by bacteria,
123 protozoans and meiofauna. The interstitial system processes organic materials flushed into
124 the sand and returning the inorganic nutrients to the sea (Pearse et al., 1942).
- 125 2) Incohesive substrate as a driver of burrowing mechanisms of macrofauna. “Dealing with
126 substrate” defines essential traits of organisms inhabiting the surf zone (Gibson et al.,
127 2006). On the supralittoral area, substrate and non-substrate modifiers can be found,
128 whose presence largely depends on substrate granulometry and related water retention,
129 as well as on allochthonous inputs (e.g. seagrasses mats) (Pérès and Picard, 1958, Sassa
130 and Yang, 2019).

131

132 **5. Vertical dimension (depth).**

133 The depth of sediment mixing is rather difficult to define, though it is generally considered from
134 the physical point of view as the layer of sediment mixed by waves over a specific time interval. It
135 depends on wave energy and sediment size, and influences the substrate-related activities of
136 benthic fauna. Resident bivalves were estimated to completely re-work the first 5 cm of fine
137 sediment, producing fecal pellets moved by the currents that caused high turbidity and a sediment
138 loss of about 30 cm/year (Risk and Moffatt, 1977). The biotic feature which best describes the
139 interaction with the vertical dimension is the biological trait of bioturbation that is functionally
140 relevant for the ecosystem (see e.g. van der Linden et al., 2012). While the relevance of burrowing
141 for organisms inhabiting the benthic of marine and lower littoral was thoroughly investigated (see
142 e.g. Gibson et al., 2006; Che and Dorgan, 2010), the upper littoral system was overlooked and only
143 recently explored (Sassa and Yang, 2019, Celentano et al., 2019). Specialist and generalist species
144 can be defined with respect to burrowing patterns: substrate specialists such as cirrolanid isopods
145 are burrowing in fine sand only and within a narrow range of water saturation conditions
146 (Giménez and Yannicelli, 2000), while generalists such as ghost crabs can display a range of shifts
147 in zonation and behavior across the littoral and cope with severe impacts, e.g. those from off-road
148 vehicle driving, by shifting burrowing behaviour (Gül and Griffen, 2018). Ecological categories can
149 also be defined within single taxonomic groups based on their burrowing capabilities (Lowry and
150 Fanini, 2013). Burrowers and non-burrowers can coexist on a soft littoral substrate, yet have a
151 different reaction to substrate disturbances, such as wrack removal (Fanini and Lowry, 2016).

152

153 **6. The concept of LAZ extended to other interface systems: Salt marshes.**

154 Salt marshes are intertidal environments also characterized by soft sediment. They have been
155 included in recent conceptual frameworks regarding human-environment interactions on soft-
156 sediment coastlines, namely as low-energy extreme environments (Dugan et al., 2018 and within).
157 Such conceptual extension would allow, as a consequence, the broadening of questions from
158 mesoscale (in its ecological meaning) to landscape ecology (Schlacher et al., 2015). Sandbanks of
159 salt marshes are also featuring the flood and drain of salt water, though with a higher material
160 retention, sharing most abiotic and biotic characteristics of sandy beaches. The identification of a
161 LAZ for salt marshes can be based on the features shared with sandy littoral zones, such as:

- 162 1) The exchange of energy and material landwards and seawards. The low and high marsh
163 behave in this respect as the beach and dune continuum. Salt marshes would represent
164 systems with low-energy exposure (see also Dugan et al., 2018), low mixing of the
165 substrate –a feature likely enhancing the role of biota in sediment mixing and making it
166 available for tidal current transport. In tidal channels however, physical processes might be
167 dominant.
- 168 2) The biotic components of salt marshes, representative of a sea-land interface with the
169 same dominant categories of species found on sandy littorals. Assemblages are defined by
170 abiotic filtering and biotic interactions, likely changing with saltmarsh succession (Scharma
171 et al. 2012). Where the flood frequency is high, marine species gain relevance (see e.g.
172 Kneib 1984, Levin and Talley 2000), while high marshes are hosting more terrestrial fauna
173 (Pétillon et al. 2008), whether specialist or temporary.
- 174 3) The effect of salinity: many terrestrial species like spiders display better survival and
175 increased fitness under non saline conditions (see e.g. Foucreau et al. 2012) while few taxa
176 act like marine species, i.e. with enhanced survival and fitness when exposed to salt stress
177 (see e.g. talitrid amphipods, Persson 2001).
- 178 4) Like beaches, salt marshes function as “islands”, from both population (genetic diversity)
179 and assemblage (species richness) points of view (see e.g. Desender et al. 1998 and Rey
180 and Strong 1983 respectively). Furthermore, patches of vegetation within a landscape
181 matrix dominated by another plant species also act as “islands within islands” (Puzin and
182 Pétillon 2019).
- 183 5) The provision of a range of ecosystem services, most relevant being: fish nursery, trophic
184 enrichment for aquaculture, aesthetic value for real estate and attenuation of waves
185 (Adams 2020). With respect to sandy beaches, salt marshes are typically less affected by
186 direct human impacts such as tourism. Yet, they are subjected to a range of anthropogenic
187 activities such as sheep grazing or mowing.

188 As low-energy systems, sand banks of salt marshes would indeed represent an extreme condition
189 of dissipative beaches (McLachlan et al., 2018), with lower turbulence and smaller substrate grain
190 size allowing the most benign conditions to biodiversity and life-history traits of resident
191 populations. An extended surf zone would allow for richer surf-fish assemblages. Finally, in a

192 metapopulation perspective, they would act as sources like flat and dissipative beaches (Defeo
193 and McLachlan, 2013) –as opposed to oceanic exposed, reflective beaches acting as sinks.

194 An opportunity to test the “sandy beach model” on other interface systems would increase the
195 relevance of coastal studies, specifically addressing the role of environmental heterogeneity in
196 granting refugia, resilience and diversity to the coastal system (Schoeman et al., 2014). Even
197 though merging fields which traditionally have been kept separated is challenging (Orr et al., 2020),
198 the relevance of LAZs is a suitable common denominator for the approach to different interface
199 systems.

200

201 **7. Social-ecological systems: human modified littorals.**

202 The anthropogenic modification of the shoreline relates to different aspects. Coastal squeeze
203 (Defeo et al., 2009; Elliott et al., 2019) is the trend resulting from the combination of actions
204 undertaken to first extend and then preserve the infrastructures and properties on the land-side,
205 coastal erosion and sea-level rise on the sea side. Changes in the near future are expected to occur
206 on and strongly affect the LAZ: urbanization, increase of population on the littoral, increasing
207 demand for recreation, climate change-related phenomena, and will likely affect its patterns and
208 processes. To address coastal squeeze, two classical actions are: 1) retreat and 2) defend (Williams
209 et al., 2018). Considering coastline retreat implies the knowledge of land uses behind the LAZ, i.e.
210 a likely difficult ecosystem analysis at short- and mid-term scales (though, different perspectives
211 based on species-environment models are proposed by Mendoza-Gonzales, 2013). As a general
212 assumption, when the natural boundaries of the LAZ are preserved (particularly the sand
213 reservoirs and the vegetation) the system can resist stress or recover from stress (resilience),
214 acting as a natural buffer against storms and natural erosion (see e.g. Sutton-Grier et al, 2015).
215 “Defend” implies human interventions which are directly and irreversibly modifying the LAZ, for
216 instance: hard infrastructures introducing fixed elements in a mobile sediment environment
217 transform a sand coast into a rock one -this is also true for non-defense hard infrastructure, such
218 as harbors, piers and artificial reefs for fishing. This should interrupt the continuum, defining new
219 beach units in terms of both abiotic and biotic components (Fanini et al., 2009; Dugan et al., 2018),
220 and beaches increasingly becoming man-made landscapes (a temporal follow-up provided by
221 Nordstrom, 2014). The extension of infrastructures on the sea side was defined as “ocean sprawl”.
222 Hypotheses on multi-scale effects of ocean sprawl on soft sediment coastlines were formulated
223 (Heery et al., 2017) yet they remain to be tested, especially regarding the effects on biota and

224 dynamics such as e.g. connectivity. For instance, as the longitudinal connectivity (structural and
225 functional) of LAZ biota and the role of marine wrack inputs are poorly studied, the research on
226 the effects of man-made fragmentation is likely to be built on missing baselines. Finally, human
227 intervention can relate to the stabilization of dunes via introduced plant species, see e.g. the use
228 of *Casuarina* ssp. and related interference with sea turtles' nesting(De Vos et al., 2019) or the
229 effects of the plant *Ammophila arenaria* replacing native species in Australia (Bird, 2000).

230 Human activities occurring on the LAZ can also be periodical and/or with reversible effects, such as
231 direct trampling and wrack removal. These kind of pressures are mostly related to recreation and
232 are sharper in case of seasonal use of the resource beach. On one hand, these impacts are related
233 to substrate changes and depletion of organic input, mainly affecting the fauna inhabiting or
234 foraging on the beach and upper part of the LAZ, where wrack inputs are a relevant feature and
235 sustain dynamics of faunal succession (Dugan et al., 2011). Supralittoral fauna can in fact actively
236 reach the wrack when available, but also display opportunistic diet shifts given the patchy and
237 discontinuous availability of the resource(Olabarria et al., 2007, Colombini et al., 2000).This latter
238 aspect is however exacerbated by human actions(reviewed by Dugan and Hubbard, 2010). On the
239 other hand, recreation is connected to a primary role of the landscape, including substrate
240 characteristics as one important feature (Pranzini et al., 2018). The presence of stranded material
241 (paradigmatic are the cases of *Posidonia* banquettes in the Mediterranean Sea, and *Sargassum* in
242 Mexico and Caribbean Islands) is perceived as negative for tourism and consequently local
243 authorities/managers are actively removing stranded material, at least seasonally. It is worth
244 remarking that along the range of impact affecting soft sediment coastlines as social-ecological
245 systems, the sand bank of salt marshes would represent a lower impact level, allowing for a
246 "compare and contrast" approach.

247 Though, regulations and management add a mismatching layer to the system, with the blanket
248 term 'littoral' including the non-aligned definitions based on different disciplines, and
249 encompassing a range of environments with specific features and processes (McLachlan and Defeo,
250 2017).

251

252 **8. LAZ as a relevant functional social-ecological unit.**

253 To summarize the concept of social-ecological unit and tie it to the LAZ, we apply the conceptual
254 scheme proposed by Bretagnolle et al., 2019 (Figure 1).The reasons of identifying the LAZ as a
255 socio-ecosystem are rooted in two backing concepts:

- 256 • The consideration of mobile substrates, physically defining the LAZ and common
257 denominator across social and ecological template is a relevant background for such an
258 integrated approach.
- 259 • The consideration of time as fourth dimension, with the identification of different temporal
260 scales highly depending on the phenomena which should be observed. The proper
261 selection of a time scale will allow an understanding of changes across both templates.

262 [Figure 1. Littoral Active Zone as social-ecological system (definition of the templates after
263 Bretagnolle et al., 2019). The boundaries of the system are considered in the three dimensions
264 physically defined in this paper.

265 The social template of the LAZ is characterized by a strong land-bias. While there is no human
266 resident on the LAZ, there is a physical direct use of the zone, as well as regulations in place to
267 define such use. At the same time, citizens have been indicated as “missing layers” in marine
268 spatial planning (Martin and Hall-Arber, 2008), neglecting a fundamental component of the social
269 template. Perceptions and attitudes of citizens are powerful drivers of the system. Hence,
270 providing literacy and awareness can bring considerable change. However, when referring to the
271 Littoral Active Zone as defined, this may indeed be a difficult background for the creation of
272 awareness, in terms of both biota and physical processes. Beaches appear as piles of sand
273 inhabited by cryptic and non-appealing key species (Dugan et al., 2010). Even high rates of
274 endemism do not result as appealing as iconic species, probably because most animal species are
275 composed of small and colorless (invertebrate) species (Harris et al., 2014; Leandro et al. 2017).
276 Iconic species are usually LAZ facilitative and were therefore found to be less responsive to
277 changes than resident fauna (Schoeman et al., 2014), even though may be key for conservation
278 (McLachlan et al., 2013).Another common issue is the perception of what component of the
279 stranded material is really litter: attitudes towards stranded wrack are generating conflicts
280 between conservation and recreation for decades. A few key drivers acting on the LAZ are
281 summarized and represent potential conflicts between conservation vs. exploitation.

282 **Tourism.** Beyond the budgetary consideration applied in geomorphology (input and output
283 estimates), square meters of substrate are a unit used for the estimate of surface available for

284 seaside activities that can be given a market value. In California, for every \$1 spent on beach
285 nourishment in Miami, the federal government expects to collect \$320 in tax revenues from beach
286 tourism (Houston 2008), while a conservative estimate of \$587 million per year is estimated as
287 value of beach visits in Queensland, Australia (Rolfe and Gregg, 2012). In general, the “Big five” for
288 beach attractiveness are: Water colour, Beach cleanliness, Safety, Facilities and Scenery (Anfuso et
289 al., 2018). The choice of a given place as a tourist destination is driven by both domestic and
290 international market pressures, hence mainly external to the LAZ. In this sense the use of Blue Flag
291 is a most relevant example of driver, considering environmental quality along with social
292 parameters (such as safety for swimmers) within the same set of desired conditions. The Blue Flag
293 award was found to increase market competitiveness of beaches (Dodds and Holmes,
294 2020). However, the concept is often confused with touristic promotion, and increasing
295 information about underlying criteria would be required (Lucrezi et al., 2015, but see McKenna et
296 al., 2011). This stresses again the importance of citizen literacy and awareness in exploiting the full
297 potential of an existing and well established tool.

298 **Cultural value.** This is a value often overlooked, in spite of being a potentially powerful driver of
299 decision making. There is a clear context-dependency related to the cultural value of littoral active
300 zones, depending on the history, social attitudes and size of population benefitting from it (Daniel
301 et al. 2012). Processes modifying cultural assets, and specifically impacts (e.g. plastics,
302 nourishment, urban sprawl) can be a leverage to engage citizens. Attitudes depend on cultural
303 value and historical use of the beaches, with biased choices stemming from human expectations
304 on sandy shores (mainly driven by recreation, real estate values, etc.), rather than on the balanced
305 representation of the system. This finally leads to unpredictable long-term consequences (Elliott et
306 al., 2007). There is an increase in different programs (among them, citizen science programs –Earp
307 and Liconti, 2020) and measures proposed by NGOs and land managers to re-connect people to
308 the ecosystem, both with respect to its functioning as a whole (in the case of LAZ phenomena such
309 as trophic network, erosion) and targeted conservation issues (ecosystem and/or species–focused
310 approach). It is too early to describe LAZ-based experiences, as many of these actions are just
311 starting, though platforms such as Ocean Best Practices and European Citizen Science are
312 preparing the environment for sharing them.

313

314 **Fishery.** This category holds a commercial interest, which, around soft-sediment shores, is
315 generally related to subsistence, recreational or commercial (listed in an increasing spatial scale of

316 relevance), though they usually co-occur (McLachlan et al., 1996). While subsistence relates mainly
317 to direct harvesting, e.g. of clam populations, and even when commercial, it is still related to the
318 artisanal and local levels, commercial fishery extends from the surf zone to the pelagic one, with
319 nursery areas for pelagic and demersal species. Lack of management plans encompassing the
320 whole species-habitat creates severe impacts, see e.g. the sequential fisheries. These are spatially
321 segregated fleets affecting different components of the life stage of one or more fish species (Seijo
322 et al., 1998).

323 **Connected templates.** In the extended LAZ concept, we link the social template to the biophysical
324 template with the adaptive management loop. In practice, in the governance of LAZ, there might
325 be mismatches between ecological units and administrative/managerial ones. The latter ranges
326 from international to national to local, and can be site-specific. An ubiquitous and trans-
327 disciplinary risk is the excessive consideration of recreation at the expenses of the other
328 components. The perceived conflict “conservation vs. exploitation” is also expected to harshen in
329 a context of climate change eroding the available resources. Even though scientific input has been
330 used to set standards, there has been inadequate integration of costs of management and
331 benefits of controls (McLachlan and Defeo, 2017). For instance, eventual discrepancies between
332 the environmental degradation perceived by the public and policy-makers with those identified by
333 scientists will need to be identified and evened up via information sharing. Several countries have
334 specific requirements for developing and implementing littoral protection; the immediate priority
335 is to avoid further development on areas likely impacted by erosion in the future, measures are
336 hence based on coastal setbacks, allowing for retreat, fixing a minimum distance from the shore
337 for new buildings. There is a huge variability worldwide regarding this distance (from 5-15 m at
338 Bahamas to 300 m in Denmark; though 100 m is the most common distance allowed. Depending
339 on the geomorphology of the coastline, in some cases such as Australia elevation becomes the
340 parameter to set limits on). Though, the way different references points are defined for “shore” –
341 e.g. low water mark; line of stable vegetation; etc. are adding further variability (see Simpson et al.,
342 2012).

343 The loop between biophysical template and social template is representing the challenge of
344 ecosystem-based governance. Even though the set of ecosystem services provided by sandy littoral
345 zones is broad, it is mostly localized and occurs within the LAZ, and tightly related with coastal
346 management units (Sardà et al., 2014). The fluid nature of the system is challenging the attempts
347 to estimate and value ecosystem services, e.g. mapping and land cover changes, a powerful tool

348 for (Burkhard et al., 2012) could not be applicable in a context of an always varying extension of
349 the area, and mobile substrate. In particular, if the littoral area -or the LAZ as we proposed- is
350 widely neglected in the international legislation as a management unit. Instruments for integrated
351 approaches to standardise development and management include a triple bottom line (TBL)
352 approach, a well-established framework with multiple stakeholder input used to account for social,
353 economic, and environmental impacts of management options. This should produce ecologically
354 meaningful and protective standards for any jurisdiction which could effectively be applied to the
355 LAZ.

356

357 **9. Application of LAZ extended concept to a coastal region: the case of Brittany**

358 As a test for this approach, after structuring the information on biophysical and social templates
359 around the concept of LAZ, we applied it to the coast of Brittany, filling with detailed information
360 related to the templates and the LAZ of a so far overlooked case, such as European macrotidal
361 shores. Questions to support further research are listed as part of the interfaces between
362 templates (ecosystem services and adaptive management: Table 1).

363 The coastline of Brittany represents 33% of the French (excluding overseas) coastline. The study of
364 its soft sediment shores is however overlooked. As mentioned above, this is not only a regional
365 need, but also a requirement to test current ecological paradigms by adding inputs from
366 macrotidal conditions (see McLachlan and Defeo, 2017; Fanini et al., 2020). Indeed, the high
367 variability and case-dependency of littoral ecology should warn against the use of “one size fits all”,
368 and the concept of LAZ as a unit should help in tackling the biophysical and social dimensions, in
369 which phenomena can be observed and described reducing the bias due to mismatching scales.
370 The structure of information in biophysical and social templates (Figure1) allows for the
371 identification of those features supporting the interfaces between templates, sustaining their
372 inter-connection via a double loop. A set of actions is recommended to assist with the
373 implementation of social-ecological governance, integrating templates along their interfaces:

374 **Ecosystem services interface (from biophysical to social).**

- 375 • Consider relevant beach units including substrate characteristics. The Breton coastline is
376 heterogeneous with a mix of rocks and soft substrates as well as different tide types (from
377 macrotidal regimen to tidal flats). A flexible yet biophysical-based unit such as the LAZ
378 would be a meaningful framework for mapping management and related effects.
- 379 • Focus research on connectivity taking into account the conditions of macrotidal shores, the
380 presence of cricks, and human modification of the coastline. Cases such as: species

381 distribution ranges (e.g. the coastal spider *Halorates reprobus* reported to have the
382 Southern boundary of its distribution range in Brittany, Courtial and Pétillon, 2016; *Crambe*
383 *maritimum* and its clustering along European coasts, Kadereit et al., 2005) and/or species
384 disappearance (such as the carabid *Eurynebria complanata* and the earwig *Labidura riparia*,
385 Courtial 2013) could open paths to the study of structural and functional connectivity
386 based on the heterogeneity of the coastline, backing the recorded patterns with their
387 drivers, and provide inputs to conservation strategies.

- 388 • Use the available knowledge and resources to define the role of wrack and of green tides
389 on the LAZ. Answer questions related to the interactions between substrate (cricks, soft
390 bottom)and stranded material interaction; test hypotheses (so far general such as e.g. in
391 Trehwella and Hatcher, 2015) on the role in the trophic chain of amphibians and mammals
392 (including bats and mustelids, so far overlooked in studies) foraging on beach wrack,
393 and/or on local fauna successions in the dynamic process of stranded material
394 decomposition (as reported by Colombini et al., 2000 for tropical shores). Disentangling the
395 temporal dimension of cast wrack and the fauna depending on it, would greatly support
396 management actions.
- 397 • Consider salt marshes as extremes not only environmental (i.e. lowest energy soft
398 sediment systems), but also in terms of social use (i.e. lowest human impact) and include
399 them in analyses across a set of conditions, from open oceanic to sand banks of salt
400 marshes. Brittany hosts one of the largest intertidal areas worldwide, with the Mont Saint-
401 Michel Bay extending to Normandy on the East, and would be a paradigmatic example in
402 this respect.
- 403 • Depict scenarios in terms of composition and quantity of seaweed beach wrack under
404 global warming and eutrophication and seaweed exploitation conditions. Answer questions
405 related to the shift in beach wrack management and in the definition of ecological
406 synchronies (e.g. the co-occurrence of spring beach wrack deposition due to lifecycle of
407 kelp and the refueling of birds during their pre-breeding migration).

408

409 **Adaptive management (from biophysical to social).**

- 410 • Consider the current littoral protection framework and the objectives of its establishment:
411 in France, all littoral areas are concerned against urbanization-artificialization by the “Loi
412 Littoral” (law n°86-2, 3 January 1986). The law relating to the development, protection and
413 development of the coast, known as the coastal law, is a French law which aims to regulate

414 the development of the coast for the protection of the excesses of real estate speculation
415 and to allow free public access to coastal paths. The limit to the building in a buffer strip of
416 100 m along the littoral is included within this legal framework. Beyond a setting against
417 unbridled urbanization, the law mentions: "The implementation of a research and
418 innovation effort focusing on the resources of the coast"; The sustainability of an aquatic
419 economy: "the preservation and development of economic activities linked to proximity to
420 water, such as fishing, marine farming, port activities, shipbuilding and repair and maritime
421 transport"; The sustainability of a non-aquatic economy: "the maintenance or
422 development, in the coastal zone, of agricultural or forestry activities, industry, crafts and
423 tourism.". However, resources and implementation of these aims rely on other actors,
424 which for Brittany are mainly (in terms of surface concerned): 1) the Natura 2000 network
425 (Habitats Directive 92/43/CEE and Bird Directive 2009/147/CE;
426 https://ec.europa.eu/environment/nature/natura2000/index_en.htm), an European
427 network based on local management plans. In France, it is mainly base on a contractual
428 approach for the management of the sites, and counts on steering committees including
429 main stakeholders (fishermen, farmers, landowners, users and experts) with the ultimate
430 goal of maintaining or restoring a good conservation status in accordance with the
431 protection of species and habitats of European interest. A large part of the Breton littoral is
432 covered by Natura 2000 areas ([http://carmen.developpement-](http://carmen.developpement-durable.gouv.fr/10/Nature_Paysage.map)
433 <http://www.conservatoire-du-littoral.fr/>). 2) the "Conservatoire du Littoral"
434 <http://www.conservatoire-du-littoral.fr/>, a governmental agency who since 1975 acquires
435 littoral areas to protect them against artificialization (currently they own around 15% of
436 French coast). As a result, the most sensitive coastal areas are under legal protection
437 against impactful activities (e.g. vehicles on the littoral), while remaining open to public.
438 Activities at the sites have to be carefully managed by local partners. 3) Natural Heritage
439 Park, Man and Biosphere Reserve and Marine National Park are large areas associated with
440 cultural values and traditional natural resource management systems where the main goal
441 is a sustainable use of natural resources (IUCN protected areas Category VI Locke and
442 Dearden 2005)

- 443 • Make best use of the impressive availability of data from LTERs and from specific groups
444 (e.g. ornithologists). The information has to be communicated to the coastal zone users in
445 the form of specific campaigns, focusing on the LAZ as a continuum and land-sea interface.
446 Specifically, raise awareness on the role of wrack and in particular of *Ulva* to sustain

447 governance with respect to a debated topic and involving possible human health issues.
448 Within a vision of beach users engagement and promotion of conservation, implement
449 actions targeting perception, e.g. investigating on the public awareness and attitudes
450 towards LAZ resident fauna (Leandro et al. 2017); debunk incorrect perceptions (e.g.
451 beaches seen as piles of sand), and counteract the standardization of beach scenery (see
452 Anfuso et al., 2018), acknowledging and valuing the individual “personality” of each beach.

- 453 • Capitalize the existing citizen monitoring programs to provide standardized, high quality
454 data at LAZ level. The example of California, where major changes in space and time were
455 identified (e.g. Hubbard et al., 2014, reporting local extirpations) due to their long-term
456 and large scale perspective, could be supported by fine-scale citizen monitoring actions.
457 The very same actions could also facilitate the integration of conservation issues in
458 management of shoreline and ultimately the empowerment of volunteers (but see the
459 aims of Plages Vivantes, a citizen science program of the National Museum of Natural
460 History, Paris www.plages-vivantes.fr).
- 461 • Identify iconic species related to the LAZ (birds, including migrating and wintering birds, are
462 better candidates, at least on a temporal base. One example of ongoing program is the
463 specific regional action plan “PRA” “Gravelot à collier interrompu” (*Charadrius*
464 *alexandrinus*) for which there is a specific (Brittany) regional action plan “PRA”
465 [www.bretagne-vivante.org/Nos-actions/Connaitre/Les-oiseaux/Especes-rares-et-](http://www.bretagne-vivante.org/Nos-actions/Connaitre/Les-oiseaux/Especes-rares-et-menacees/Le-Gravelot-a-Collier-Interrompu/Un-plan-regional-d-action-pour-le-Gravelot-a-collier-interrompu-en-Bretagne)
466 [menacees/Le-Gravelot-a-Collier-Interrompu/Un-plan-regional-d-action-pour-le-Gravelot-a-](http://www.bretagne-vivante.org/Nos-actions/Connaitre/Les-oiseaux/Especes-rares-et-menacees/Le-Gravelot-a-Collier-Interrompu/Un-plan-regional-d-action-pour-le-Gravelot-a-collier-interrompu-en-Bretagne)
467 [collier-interrompu-en-Bretagne](http://www.bretagne-vivante.org/Nos-actions/Connaitre/Les-oiseaux/Especes-rares-et-menacees/Le-Gravelot-a-Collier-Interrompu/Un-plan-regional-d-action-pour-le-Gravelot-a-collier-interrompu-en-Bretagne)). The connection of iconic species with the significance
468 of LAZ for the completion of their life-cycle would allow for ad hoc campaigns maintaining a
469 species-environment focus. Under a management perspective, the information related to
470 iconic species is also a parameter proposed by McLachlan et al. (2013) for the allocation of
471 management priorities in the case of beach mixed use, hence this information would finally
472 find an application outlet.
- 473 • Consider LAZ units for Driver-Pressure-State-Impact-Response studies and their outcomes
474 as governance support (see e.g. Pirrone et al., 2005), keeping the environmental mesoscale
475 as the appropriate level to efficiently detect DPSIR. The mosaic of geomorphologies and
476 uses found in Brittany would in fact allow for the isolation of different phenomena at the
477 same spatio-temporal scale.
- 478 • Sustain the current asset of littoral protection, understanding the underlying mechanisms
479 which connect the range of tools available for sustainable management. This could reveal

480 mismatches between theoretical and practical frameworks. With respect to the Blue Flag
481 for example, 35 beaches (including one lake) and ten harbours were awarded in 2020 in
482 Brittany (maps at [https://bretagne-environnement.fr/dataset/communes-et-ports-](https://bretagne-environnement.fr/dataset/communes-et-ports-labellis%C3%A9s-pavillon-bleu-en-bretagne/resource/895be2a9-3280-4f83-83af)
483 [labellis%C3%A9s-pavillon-bleu-en-bretagne/resource/895be2a9-3280-4f83-83af](https://bretagne-environnement.fr/dataset/communes-et-ports-labellis%C3%A9s-pavillon-bleu-en-bretagne/resource/895be2a9-3280-4f83-83af)). However,
484 most of the sites are not located in protected areas. This is likely due to the fact that Blue
485 Flag awards in France are mainly perceived as advertising for mass tourism. Plus, the
486 award mechanism requires active application. As a result, only cities apply and eventually
487 achieve the flag, while natural and protected areas do not apply, in order to avoid
488 overtourism. Finally, because the Loi Littoral is already implementing beach quality since
489 1985, the connection between a further external driver such as the Blue Flag and
490 environmental quality is weaker than in other contexts and the impact of Blue Flag remains
491 related to the promotional aspects of tourism.

- 492 • The points listed above, the background information proceeding for this and its framing in
493 the social-ecological context would finally respond to the urgent need for specific legal
494 instruments. In fact, even if several European Directives (e.g. 2000/60/CE on the water
495 quality; 79/409/CEE for avifauna; 92/43/CEE for habitat conservation; 2008/56/CE on the
496 Marine Strategy Framework) are implemented, their framing in a social-ecological context
497 would be essential for the sustainable management of littoral ecosystems.

498

499 **10. Conclusions**

500 The use of the LAZ concept to define meaningful units as the research subject and its
501 consideration in a context like Brittany revealed 1) important information to be retrieved as a
502 baseline for soft sediment coastlines, and 2) directions for a potential extension of concepts, from
503 ecological mesoscale to landscape scale. Firstly, the consideration of substrate characteristics
504 defined the LAZ and was tightly intertwined with both biophysical and social templates. This
505 consideration aligns with the call for broadening the use of the geodiversity concept (Boothroyd
506 and McHenry, 2019), and is especially meaningful when considering physically-driven
507 environments such as soft sediment shores. In practice, information from beach or salt-marsh unit
508 level and including measurements of basic parameters such as beach profiles, granulometry and
509 rocky patches can return extremely powerful integrated datasets.

510 Considering specific features with remarkable relevance both for biophysical and social template,
511 a further recommendation - would be to retrieve baselines of biodiversity for beach units, to be
512 compared with conditions of 1) allochthonous input, including perception and management from

513 the social template and 2) spatio-temporal use of the resources by endemics and iconic species,
514 including perception and management from the social template.

515 Regarding the up-scaling to landscape ecology, the LAZ concept would likely find a place within the
516 integrated landscape approach framework as defined by Freeman et al.(2015). In this respect, the
517 conceptual extension to salt marshes is likely to open new insights into landscape ecology,
518 supported by a gradient analysis and going beyond the “compare and contrast” approach. On the
519 layout defined by such heterogeneity, the relevance and use of data from management (ranging
520 from tourism exploitation to fish nurseries for commercial value to conservation as seen from the
521 case of Brittany) would be maximized, with a shift to qualitative integrated data (Alexander et al.,
522 2019) for effective a) research on social-ecological systems and b) governance support.

523

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Highlights

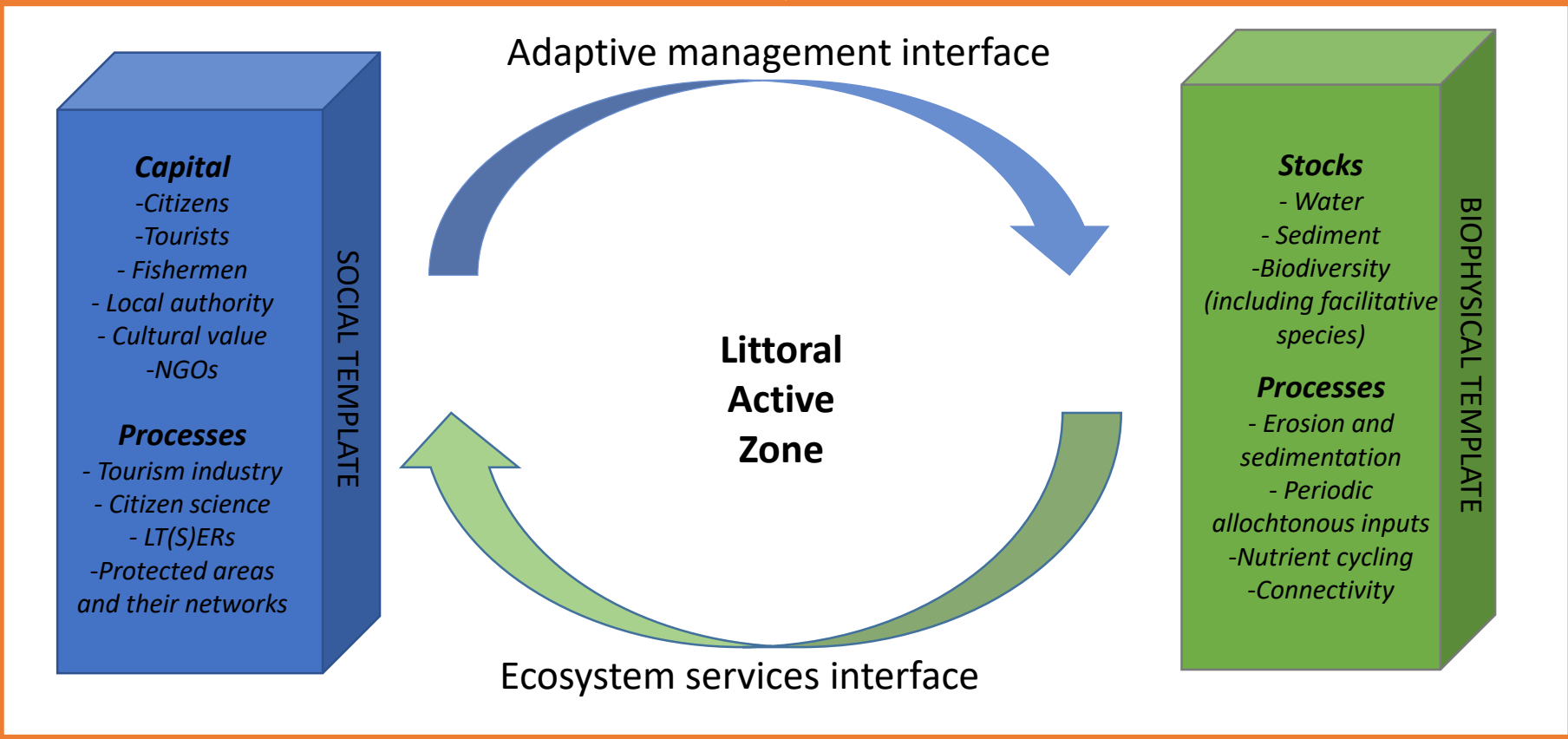
1. The concept of Littoral Active Zone of a beach unit was defined in its spatio-temporal dimensions
2. The Biophysical and Social Templates of LAZs were defined generally for beaches and salt marshes
3. The concepts were applied to the case of the coastline of Brittany
4. The LAZ concept proved to be a suitable to define system patterns and drivers

Table 1. Features of Ecological and Social Templates specifically referring to the Littoral Active Zones of Brittany Region.

Ecological Template	Social Template
The coastline is defined by macrotidal regimen and tidal flats	The management of coastal areas includes Long Term Social Ecological Research Stations (LTSER Zone Atelier Brest Iroise and LTSER Zone Atelier Armorique) along the coast. The many protected areas include the Iroise Marine Natural Park (first national marine park in France, established in 2007) or the Sept Iles natural reserve (First protected area in France established in 1912).
Salt marshes are present, along with embayments and exposed coastlines.	“La Loi Littoral” in France prohibits since 1986 any new building outside the existing town in a buffer strip of 100m from the highest water level along sea and lake shores and is applied in Brittany.
<p>The coastline presents “cricks”, i.e. a mix of rocks and soft substrate. Cricks are likely to affect substrate mobility and dynamics in both across-and along-shore dimension of the LAZ.</p> <p>They are also likely to provide microhabitats at the interface between rocky and soft sediment.</p>	<p>Long term datasets related to fauna and environmental factors are being gathered and made available via LTSERs https://deims.org and the Seashore and coastal research infrastructure (https://www.ir-ilico.fr/en/).</p> <p>Citizen science actions are in place, on single beaches yet covering, as concerted actions, at landscape scale (Plages Vivantes, MNHN https://plagesvivantes.65mo.fr/ and CapOeRa https://www.asso-apecs.org/Principes-du-programme.html) and focus on beached wrack.</p>
<p>Stranded wrack is a pulse resource (Leroux and Loreau, 2008; 2012), related to the use of beach by a community of invertebrates (i.e. Amphipoda <i>Gammarus locusta</i>, <i>Orchestia gammarellus</i>), Diptera (<i>Coelopafrigida</i> spp.)) that decompose wracks (Zemke-White et al., 2005; Olabarria et al., 2007) and are an important resource for other organisms including iconic species: the</p>	There is a range of management choices related to wrack, with removal mainly influenced by tourism demand (GRoupe d’ETude des Invertébrés Armoricaine report, Courtial, 2013).

External constraints

- Climate (temperature, wind, storm) and Sea level
- Social perception / attitudes
- International legislation/convention
- Tourism market (domestic and international)
- Real estate market



rock Pipit (*Anthus petrosus* spp.) -with a very restricted distribution area limited to the LAZ- and migratory birds for which the decomposer of stranded wrack are a needed resource during their stopover, turnstone (*Arenaria interpres*) and purple sandpiper (*Calidris maritima*) (Kerbiriou 2016). Even though there is a lack of studies related to the food-web associated to stranded wrack as pulse resource, this is also hypothesized to be relevant to others terrestrial vertebrates such as toads and bats (Trehwella and Hatcher 2015).

Some beaches are periodically affected by green tides (*Ulva*)(Charlier et al. 2007), which proliferation and accumulation is related to the conjunction of the natural confinement of some shallow water masses, despite the strong tidal movement, and a nitrate terrestrial load from agricultural origin (Menesguen 1992 but also see <https://www.ceva-algues.com/en/>).

Green tides occur during spring and summer and has been detrimental to recreational use of several beaches of Brittany and consequently in littoral tourism economy (Menesguen 1992).

The region has a high value related to tourism. Brittany is the fourth region of France in terms of number of nights for tourism (more than 20 million nights/year of which around 17 million located on the littoral areas after INSEE 2019, see <https://insee.fr>). The most attractive touristic localities are the Mont St Michel Bay, the Morbihan Gulf and the Quiberon Peninsula (but also see <https://www.brittanytourism.com>).

The cultural heritage of Brittany is also very important to the social template: this is the last region attached to the France kingdom in 1532, but it retained its cultural distinctiveness throughout centuries (e.g. Celtic language, music, traditional dress).

The “Conservatoire du littoral” is a French governmental organization established in 1975, buying stretches of coastline to apply conservation-oriented management while keeping it open to the public. Currently manages 15% of the French coastline (but see for Brittany http://www.conservatoire-du-littoral.fr/sites-du-littoral/SIL_SYCLAD_REGION/BRETAGNE/Find/1/5-les-sites-du-littoral.htm)

Brittany is the first French region for fishing, with around a half of the national marine production (fish, seafood and algae) (AGRIMER 2019, <https://www.franceagrimer.fr>), as well as the first agricultural region of France with 10% of the national agricultural and fish production (INSEE 2019).
