



# The extended concept of littoral active zone considering soft sediment shores as social-ecological systems, and an application to Brittany (North-Western France)

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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

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

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

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

### **3. Across-shore dimension.**

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

### **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:

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

As low-energy systems, sand banks of salt marshes would indeed represent an extreme condition of dissipative beaches (McLachlan et al., 2018), with lower turbulence and smaller substrate grain size allowing the most benign conditions to biodiversity and life-history traits of resident 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

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

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

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

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

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

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

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

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

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

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

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

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

- governance with respect to a debated topic and involving possible human health issues. Within a vision of beach users engagement and promotion of conservation, implement actions targeting perception, e.g. investigating on the public awareness and attitudes towards LAZ resident fauna (Leandro et al. 2017); debunk incorrect perceptions (e.g. beaches seen as piles of sand), and counteract the standardization of beach scenery (see Anfuso et al., 2018), acknowledging and valuing the individual “personality” of each beach.
- Capitalize the existing citizen monitoring programs to provide standardized, high quality data at LAZ level. The example of California, where major changes in space and time were identified (e.g. Hubbard et al., 2014, reporting local extirpations) due to their long-term and large scale perspective, could be supported by fine-scale citizen monitoring actions. The very same actions could also facilitate the integration of conservation issues in management of shoreline and ultimately the empowerment of volunteers (but see the aims of Plages Vivantes, a citizen science program of the National Museum of Natural History, Paris [www.plages-vivantes.fr](http://www.plages-vivantes.fr)).
  - Identify iconic species related to the LAZ (birds, including migrating and wintering birds, are better candidates, at least on a temporal base. One example of ongoing program is the specific regional action plan “PRA” “Gravelot à collier interrompu” (*Charadrius alexandrinus*) for which there is a specific (Brittany) regional action plan “PRA” [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](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 of LAZ for the completion of their life-cycle would allow for ad hoc campaigns maintaining a species-environment focus. Under a management perspective, the information related to iconic species is also a parameter proposed by McLachlan et al. (2013) for the allocation of management priorities in the case of beach mixed use, hence this information would finally find an application outlet.
  - Consider LAZ units for Driver-Pressure-State-Impact-Response studies and their outcomes as governance support (see e.g. Pirrone et al., 2005), keeping the environmental mesoscale as the appropriate level to efficiently detect DPSIR. The mosaic of geomorphologies and uses found in Brittany would in fact allow for the isolation of different phenomena at the same spatio-temporal scale.
  - Sustain the current asset of littoral protection, understanding the underlying mechanisms which connect the range of tools available for sustainable management. This could reveal



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

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

## 10. Conclusions

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

Considering specific features with remarkable relevance both for biophysical and social template, a further recommendation - would be to retrieve baselines of biodiversity for beach units, to be 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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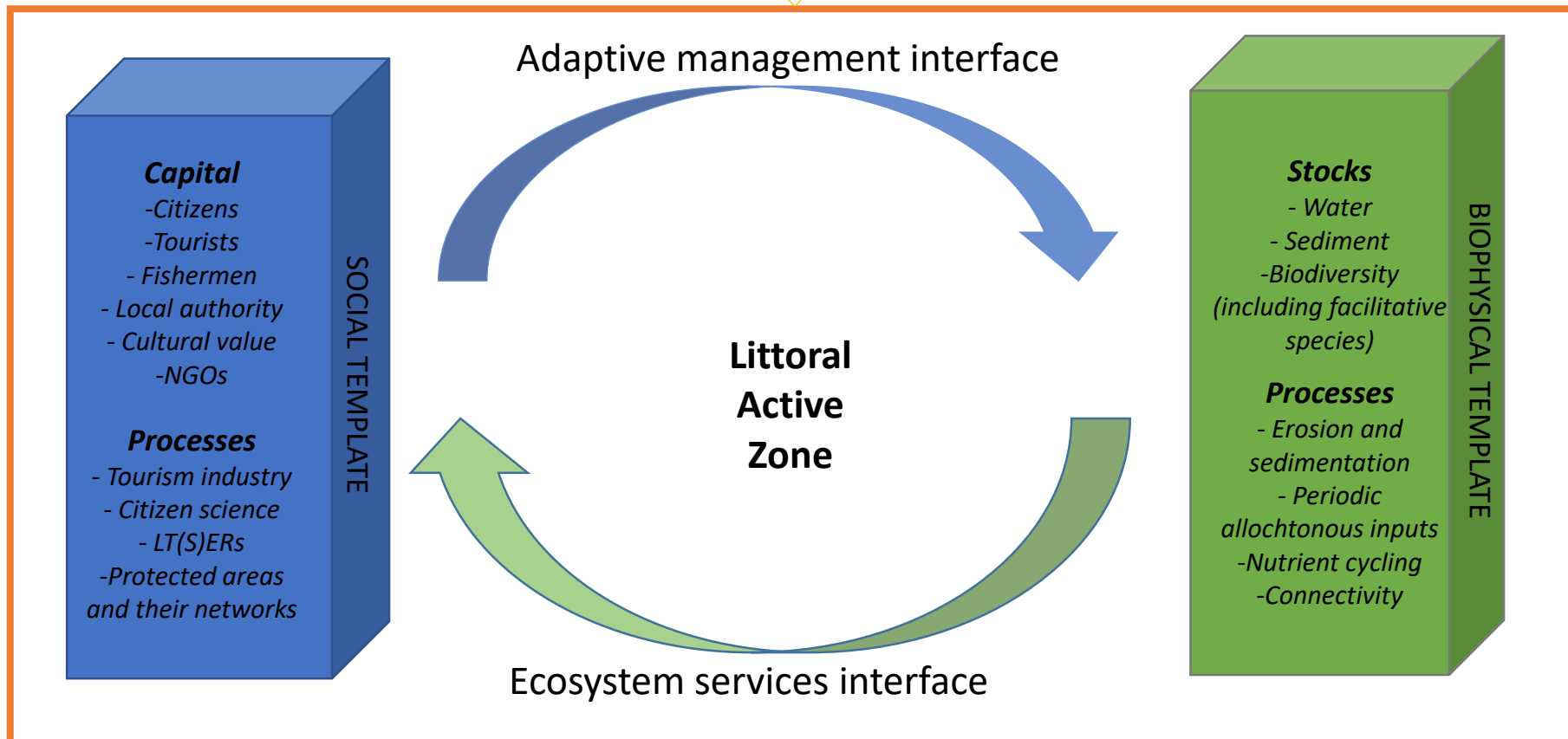
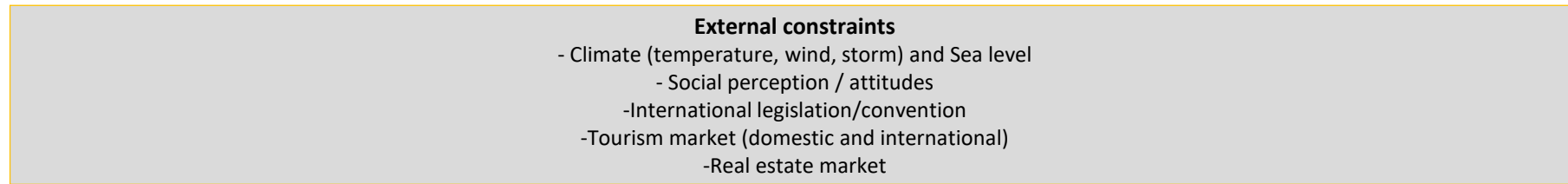
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## Highlights

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 <a href="https://deims.org">https://deims.org</a> and the Seashore and coastal research infrastructure (<a href="https://www.ir-ilico.fr/en/">https://www.ir-ilico.fr/en/</a>).</p> <p>Citizen science actions are in place, on single beaches yet covering, as concerted actions, at landscape scale (Plages Vivantes, MNHN <a href="https://plagesvivantes.65mo.fr/">https://plagesvivantes.65mo.fr/</a> and CapOeRa <a href="https://www.asso-apecs.org/Principes-du-programme.html">https://www.asso-apecs.org/Principes-du-programme.html</a> ) 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 sspp.</i>)) 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 Armoricaïne report, Courtial, 2013).



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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).

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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/> ).

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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).

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The region has a high value related to tourism. Brittany is the forth 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> ).

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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).

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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](http://www.conservatoire-du-littoral.fr/sites-du-littoral/SIL_SYCLAD_REGION/BRETAGNE/Find/1/5-les-sites-du-littoral.htm) )

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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).

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