



HAL
open science

Managed retreat of settlements and infrastructures: ecological restoration as an opportunity to overcome maladaptive coastal development in France

Timothée Fouqueray, Michel Trommetter, Nathalie Frascaria-Lacoste

► To cite this version:

Timothée Fouqueray, Michel Trommetter, Nathalie Frascaria-Lacoste. Managed retreat of settlements and infrastructures: ecological restoration as an opportunity to overcome maladaptive coastal development in France. *Restoration Ecology*, 2018, 26 (5), pp.806-812. 10.1111/rec.12836 . hal-02456982

HAL Id: hal-02456982

<https://hal.science/hal-02456982v1>

Submitted on 27 Jan 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 **Title**

2 Managed retreat of settlements and infrastructures: Ecological restoration as an opportunity to
3 overcome maladaptive coastal development in France

4

5 **Running head**

6 Restoration opportunities through managed retreat

7

8 **Authors and addresses**

9 Timothée Fouqueray (corresponding author), timothee.fouqueray@agroparistech.fr

10 Écologie, Systématique, Évolution, AgroParisTech, CNRS, Univ. Paris-Sud, Université
11 Paris-Saclay, 91400, Orsay, France

12

13 Michel Trommetter, mtrommetter@grenoble.inra.fr

14 GAEL, INRA, CNRS, Grenoble INP, Univ. Grenoble Alpes, 38000, Grenoble, France

15

16 Nathalie Frascaria, nathalie.frascaria@u-psud.fr

17 Écologie, Systématique, Évolution, AgroParisTech, CNRS, Univ. Paris-Sud, Université Paris-
18 Saclay, 91400, Orsay, France

19

20 **Author contributions**

21 TF conceived, designed, and wrote the paper; MT, NF made additional contributions and
22 edited the manuscript.

23

24 **Abstract**

25

26 The effects of climate change on coastal risk factors are increasing due to both rising sea
27 levels and increasingly intense coastal floodings. However, these changes are only just
28 beginning to be incorporated into planning strategies for coastal economies and land use in
29 France. Recent coastal storms marked the turning point, and public authorities have now
30 started to revise coastal management legislation, stating that the managed retreat of
31 settlements and infrastructure is the preferred strategy to adapt to climate change. To date, this
32 managed retreat has almost exclusively been discussed in relation to the current political,
33 social, and economic obstacles that make it difficult to relocate equipment and houses inland.
34 Here, we add to this discussion by depicting how the careful ecological restoration of dunes
35 and salt marshes on land made available by managed retreat could overcome some of these
36 obstacles. First, we describe three possible strategies to adapt to sea-level rise as well as the
37 maladaptation of the current strategy. We then focus on the limitations and advantages of
38 ecological restoration in terms of managed retreat and vice-versa. Finally, we depict how a
39 new kind of land lease, introduced in draft legislation, can help tackle the multitemporal and
40 multispatial issues that currently hinder managed retreat.

41

42 **Key words**

43 Adaptation, land use, marine submersion, restoration, sea level, social–ecological

44

45 **Implications**

46 - If restorationists do not neglect the social issues that accompany managed retreat, they
47 have a major opportunity to create, restore, and conserve dune ridges, salt marshes,
48 and their associated ecological communities on coastal land made available by
49 managed retreat.

50 - Drawing from adaptive management, draft legislation introduces “zones of

51 authorization for resilient and temporary activities” that can help serve as an example
52 of adaptation to sea-level rise for coastal land use acts in other countries.

53

54 **Main text**

55

56 INTRODUCTION

57

58 Sea-level rise (SLR) will have major consequences for populations in low-lying coastal areas
59 (Wong et al. 2014). Despite the uncertainties surrounding the expected speed and magnitude
60 of SLR (Carson et al. 2016; Cazenave & Llovel 2010), it is very likely to exacerbate long-
61 term adverse impacts of storm surges and coastal floodings (Wong et al. 2014). Adaptation
62 policies must therefore be developed to provide strategies for coping with the effects of global
63 warming on coastal areas. Defined as “adjustments in ecological, social, or economic systems
64 in response to observed or expected changes in climatic stimuli and their effects” (Adger et al.
65 2005), strategic adaptations can be considered to be either reactive (e.g., building dams or
66 dikes after coastal flooding) or proactive. Proactive adaptations are measures taken to lessen
67 the perceived negative impacts of future events (Engle 2011) such as prohibiting housing
68 construction in future coastal flood-prone areas. In France, SLR and its consequences are an
69 extremely important issue because the country’s coastlines are of great ecological and
70 economic value (Van Der Maarel 2003; Wong et al. 2014). Indeed, coastlines can be seen as
71 four interconnected subsystems: sediment cells of beaches, coastal municipalities,
72 management paradigms, and oceans, for which the spatial extent and temporal scales are
73 shown in Table 1.

74 France was affected by an almost unprecedented winter storm (storm Xynthia) in 2010, which
75 resulted in 47 fatalities and property damage estimated at €1.5 billion. More winter storms

76 three years later exacerbated erosion and damaged man-made structures (Rocle & Salles
77 2017; Cour des Comptes 2010). Such winter storms diminish atmospheric pressure enough to
78 raise the local sea level and trigger marine submersion (Wong et al. 2014). The fatalities and
79 property damage caused by these storms and consequent flooding led to a national revision of
80 coastal policies to take safety and environmental issues into consideration (Rocle & Salles
81 2017). Members of the French Parliament are currently debating updates to coastal land use
82 laws in an attempt to introduce legislative levers that favor adaptations to SLR (Lurton et al.
83 2017).

84 In this paper, we focus on a coastal adaptation strategy known as managed retreat (MR),
85 which is encouraged in the new draft of the coastal act. MR is sometimes called “planned
86 retreat” or “managed realignment” and involves an inland relocation of infrastructures
87 currently located on low-lying coastal land (e.g., coastal protection infrastructure, houses,
88 industrial and commercial areas), which is at risk of coastal flooding (Heurtefeux et al. 2011).
89 For example, a seafront road was relocated 40 meters inland between 2007 and 2012 in Sète,
90 a coastal municipality in southern France (Heurtefeux et al. 2011). In France, MR is of
91 particular interest, especially for 25% of the country’s coastlines with observable erosion
92 (around 1,700 km, of which around 1,150 km are low-lying sand coasts) (Mineo-Kleiner
93 2017), as the retreating coastline draws nearer to infrastructure and jeopardizes it.

94 We begin here by analyzing the persistent blockages of MR in certain areas. We then present
95 several precautions in order to preserve mutual social and ecological benefits of MR and
96 ecological restoration. Finally, we describe how the renewal of the coastal act presents an
97 opportunity for MR and the ecological restoration of low-lying coastal areas.

98 We first base our assessment on a review of i) peer-reviewed articles from ecology,
99 economics, geography, and political science journals, mostly published in French since storm
100 Xynthia (2010). We complete these sources with ii) the minutes of meetings on coastal

101 flooding management involving governmental agencies such as the “Conservatoire du
102 Littoral” (body responsible for preservation of the French coastline) and the “Cour des
103 Comptes” (French supervisor of public subsidies) from the same period, as well as iii)
104 European reports on erosion and coastal adaptation to SLR strategies published since year
105 2000. The review results were supplemented with an exploratory field visit of Port-des-
106 Barques in March 2017, a municipality affected by storm Xynthia in Charente-Maritime (Fig.
107 S1), as well as personal communication with coastal land use planners.

108

109 1. FRENCH COASTLINE PLANNING IS MALADAPTED TO THE EFFECTS OF 110 EXPECTED CLIMATE CHANGE

111

112 *Three strategies to adapt to SLR and marine submersions*

113

114 The effects of winter storms are expected to be exacerbated by climate change-related SLR,
115 and although sea-level estimates for 2030 do not exceed 0.07m, they vary between 0.35m and
116 1m for 2100 (Lurton et al. 2017; Vinchon et al. 2011).

117 Allison and Hobbs (2004) suggest three broad options to adapt to such crises, with different
118 intervention intensities. For municipalities that seek to prevent coastal disturbances, the most
119 interventionist strategy is “command and control,” which involves a community actively
120 fighting coastline erosion through the heavy use of technology. This strategy has been used in
121 France in recent decades (Table 1), with the construction of coastal defences such as dikes,
122 groins, seawalls, and geotextile tubes (Touili et al. 2014; Clément et al. 2015). Making
123 “adjustments” through more gentle interventions (e.g., alert systems, insurance systems,
124 flood-proof buildings) is the intermediate strategy (Cour des Comptes 2010). “MR” is the
125 third and least interventionist strategy regarding erosive processes. Relocating sea-front

126 housing, economic infrastructure (e.g., industrial areas, roads, factories), and strategic
127 buildings (e.g., hospitals, fire stations) means that humans reduce their impact on the coastal
128 ecosystem and adapt to the disturbance instead of repelling it; in this way, MR differs from
129 the default position of doing nothing and corresponds to adaptive management principles
130 (Engle 2011).

131 By relying on the expensive “command and control” strategy, French shorelines are on a
132 maladaptive trajectory, as erosive processes and natural disasters are enhanced by climate
133 change. To date, technological interventions have indeed disrupted beach accretion, and less
134 sediment has been delivered to coasts because of the trapping of riverine sediment behind
135 dams and the diversion of water for irrigation (Wong et al. 2014). Defensive structures
136 dissipate wave energy by causing upwelling and decreasing the amount of sediment deposited
137 at a particular location, thus resulting in down-drift erosion at other locations. Coastal
138 defences therefore need to be constantly extended at a high cost to human lives and society.

139

140 *French coastal municipalities persist in the “command and control” strategy*

141

142 Here, we identify the economic, political, and social obstacles that compel local decision-
143 makers to abide by their current maladaptive strategy of coastal armoring.

144 Economically, insurance companies supported the recovery of coastal inhabitants after storm
145 Xynthia. In France, these companies reimburse policy holders for damage caused by natural
146 disasters using money collected nationally from car and home insurance premiums (Clément
147 et al. 2015). However, the demand for financial compensation is likely to increase
148 unsustainably, because increasing numbers of people (due to the demographic pressure on
149 coastlines) will be exposed to more frequent and intense coastal flooding (Lambert 2015).
150 This economic connectedness of people through their insurance policies is accompanied by

151 the connectedness of the state and affected municipalities, as the former partially funds the
152 reconstruction of the latter. Coastal recovery was indeed strongly supported by public
153 subsidies following storm Xynthia. For instance, one of the main areas affected by storm
154 Xynthia, the Charente-Maritime department (Fig. S1), launched a €750,000 television
155 advertising campaign to promote beach tourism, stating that the area would recover and be
156 ready for the summer vacation period. Another €3 million was spent on restoring sea defences
157 and sand replenishment (Anziani 2010). Such sea defences are contrary to the principles of
158 MR because the authorities could simply wait for the land to become permanently submerged
159 and then claim it as a public maritime domain, a procedure similar to the United States’
160 “rolling easement system” (Siders 2013). Both the tourism-based economy and the financial
161 connectedness between inland and coastal territories participate in maintaining this
162 maladaptive “command and control” management, because the need for taking SLR into
163 account is continually postponed.

164 Socially, the reluctance to change can explain how maladaptive individual and collective
165 behaviors hinder adaptations to SLR. As a coastal community grows and becomes richer, it
166 will apply increasing pressure on local decision-makers to choose sea defences as opposed to
167 MR. For instance, following storm Xynthia, the inhabitants of Charente-Maritime demanded
168 for dikes to be built instead of demolishing vulnerable houses (Mineo-Kleiner & Meur-Ferec
169 2016). Sea defences support a false sense of security, causing counteradaptive misperceptions
170 of risks (Mineo-Kleiner & Meur-Ferec 2016). For instance, fatalities could have been avoided
171 if inhabitants trapped in flooded houses had felt vulnerable enough to participate in
172 prevention programs and learn to keep their shutters open, thus allowing for an emergency
173 exit (J. Laugraud, ex-mayor, personal communication). Ultimately, the pressure to build sea
174 defences was applied to mayors, some of whom see coastal land use as an electoral lever
175 through employment and population growth. Local political mandates last for 6 years in

176 France, which is short relative to the time required for a return on investment in MR.
177 Maladaptive policies therefore fail to reward investment in MR, because benefits are only
178 perceived in the future (Abel et al. 2011).

179 The self-reinforcing first strategy of “command and control” calls for a renewal of recent
180 French coastal policies. So how can MR be an opportunity to implement coastal ecological
181 restoration?

182

183 2. CAN MR BENEFIT ECOLOGICAL RESTORATION AND VICE-VERSA?

184

185 By releasing land, MR can be a chance to create, restore, or preserve coastal ecosystems, as
186 long as care is taken to respect the balance between socio-economic issues and ecological
187 considerations.

188

189 *Benefits and precautionary measures of MR for ecological restoration*

190

191 Above all, MR favors ecological restoration by providing habitats for coastal species: the
192 creation, restoration, and conservation of dune ridges and salt marshes benefit coastal plant
193 communities by preventing beaches from steepening and foreshortening (Feagin et al. 2005).

194 MR also improves species resilience to climatic fluctuations by providing habitats for species
195 to recolonize neighboring areas that have become eroded or destroyed (Adger et al. 2005).

196 It is also essential to avoid potentially counterproductive measures of MR in terms of
197 ecological restoration. If the target site has been recently damaged, land released through MR
198 will initially require work to bring it back to the desired environmental trajectory. For soil that
199 has been brought into an artificial state before MR or mechanically disrupted during the
200 demolition of infrastructure during MR, doing nothing favors common species at the expense

201 of species of ecological interest (Affre et al. 2015). Anthropogenic interventions try to
202 accelerate ecological recovery at a target site, as illustrated at the Sète lido, where 300,000
203 marram grass (*Ammophila arenaria*) seedlings were planted (Vinchon et al. 2011). To
204 improve respect for the site, newsletters and liaison groups were used to explain to visitors
205 why MR is important (Dixon et al. 2008).

206 On coastlands affected by MR, there may also be species that are protected or of ecological
207 interest. Cases have been reported in which translocation and rescue programs for plants and
208 animals were considered necessary for MR to be successful (Dixon et al. 2008).

209 Above all, MR involves relocating infrastructure inland, which means that natural or
210 agricultural land away from the coast is at risk of being artificialized. Indeed, the land
211 shortage in France impedes the relocation of houses and equipment to unaffected land
212 (Mineo-Kleiner 2017). There are legal safeguards to avoid displacing urbanization pressure
213 and destroying natural soils such as the prohibition to build on preserved land and injunctions
214 to relocate within urbanized areas. Yet political arbitration between the various sources of
215 local pressure on land makes the task complex, especially since electoral mandates are
216 relatively short (Table 1).

217

218 *Ecological restoration assets favoring MR*

219

220 Inversely, ecological restoration presents beneficial side effects for MR. For instance, the
221 revegetation of newly cleared land restores sediment cycling. Dune ridges and salt marshes
222 are ecosystem-based reducers of destructive wave energy, which protect the land
223 (Temmerman et al. 2013). Coupled with wave-breaking plants such as sea grass (*Posidonia*
224 *oceanica*) and eelgrass (*Zostera marina*), ecological restoration as part of MR permits the
225 effective adaptation to coastal erosion and flooding (Temmerman et al. 2013).

226 Instead of emphasizing restoration constraints, publicizing the benefits of natural processes
227 for MR encourages stakeholders with potentially contrasting interests in environmental issues
228 to work together. For example, the restoration of coastal marshes simultaneously increases
229 biodiversity, stores carbon, and limits seawater intrusion (Temmerman et al. 2013; Mossman
230 et al. 2012). Consequently, a relevant integration of the beneficial side effects of MR fosters
231 the transition from a static perspective of biodiversity to a “monitor and adapt” management
232 system (Table 1).

233

234 *Limitations of MR due to ecological restoration*

235

236 Dedicating released land to ecological restoration alone endangers the social acceptability of
237 MR. This can be counteracted by fostering tourism-based employment that relies on the use
238 of light infrastructure (e.g., moveable buildings on stilts) (Mineo-Kleiner & Meur-Ferec
239 2016). From this perspective, most MR scenarios include an economic appraisal of the
240 released land by coupling the project with low-impact economic activities. Based on
241 experience, the touristic valuation of restored coastlines is compatible with environmental
242 processes. In terms of cleaning up beaches, it is possible to retrieve non-organic waste alone
243 or leave foreshore tide marks untouched until tourists start frequenting the area. This favors
244 nucleation and the accumulation of sand on dune ridges, because it maintains the supply of
245 organic material to feed dune vegetation and allows sand sequestration (Temmerman et al.
246 2013; Lambert 2015; Wong et al. 2014). Touristic valuation also sometimes relies on shuttle
247 buses linking beaches to parking lots that no longer stand close to the seaside because of MR.

248

249 3. A DRAFT LAW TO OVERCOME MULTISCALE OBSTACLES TO MR

250

251 MR has been described as a cost-efficient long-term means of coping with the effects of SLR
252 (Abel et al. 2011), and the obstacles for its adoption are well documented. So how can the
253 draft legislation help French coastal municipalities implement MR?

254

255 *The rise of MR in research programs*

256

257 After storm Xynthia in 2010, the stakeholders who clamored for changes in coastal policies
258 were mostly insurance companies and the Cour des Comptes, or in other words, those paying
259 for the restoration. Public agencies and insurance companies try to refine their decision-
260 making by investing in efforts to decrease uncertainty (e.g., SLR celerity, recovery costs after
261 marine submersion). Consequently, scientific projects were launched in France to learn
262 lessons from storm Xynthia (Vinchon et al. 2011). The Sète lido was involved in a call for
263 proposals and partly changed from a “command and control” strategy to MR. This 12 km long
264 and 2 km wide strip of sand, which is very popular with tourists, separates the sea from a
265 lagoon on the south coast of France (Fig. S1). The lido also hosts an economic asset: the
266 renowned Listel vineyard, which has been subjected to severe coastal erosion (Heurtefeux et
267 al. 2011). A seafront road was relocated between 2007 and 2012 to allow the sand dunes to
268 recover. The dunes were made more stable using bundles of brushwood, and they now protect
269 the lido (Heurtefeux et al. 2011). MR was partly made possible, because the demand for
270 income from tourism and the support for the well-being of inhabitants, linked to the stability
271 of the beach, were strong, and because no houses had to be relocated (Mineo-Kleiner &
272 Meur-Ferec 2016). This rare case of MR is distinguished on account of its foresight and long-
273 term investment (MR cost of €54 million). Interestingly, the French state, which previously
274 granted maladaptive public subsidies for the reconstruction of sea defences, now funds
275 experimental MR. This small change points out to a transformation in the representation of

276 human interventions on ecosystems, from a static perception of coastlines to adaptive
277 management practices (Table 1), which are now echoed in the draft legislation.

278

279 *What can a new law do for MR?*

280

281 The law entitled “Adapting coastal territories to climate change” is currently being passed by
282 the French Parliament (Lurton et al. 2017). Drawing from research outputs such as Sète’s
283 results, draft legislation was developed. It is also based on experimental findings from other
284 countries, thanks to exchanges with the UK Environment Agency (Pontee 2007; Creed et al.
285 2014; Rocle & Salles 2017). The law will introduce “zones of authorization for resilient and
286 temporary activities,” a new type of land lease designed for vulnerable coastal strips. These
287 leases will last between 5 and 99 years, and tenants will be required to leave when the risks
288 exceed a threshold indicated in a prevention plan (Lurton et al. 2017) – hence the legislative
289 interpretation of “resilience” for labile and removable activities (e.g., windsurf schools).
290 Ultimately, the law will also define a “coastline mobility zone” in which natural barriers (e.g.,
291 salt marshes and dune ridges) are preferred over manmade sea defences. Governance
292 mechanisms have been designed for a smooth transition to MR, drawing on an economic
293 study of MR cost sharing (see, for example, the insights from a willingness-to-pay analysis in
294 Rey-Valette et al. [2016]).

295 The originality of this draft law is its acknowledgement of the complex social and ecological
296 interdependancies of coastal subsystems with their different spatial and temporal scales
297 (Table 1). With the new type of lease, the draft legislation offers an innovative tool to
298 implement MR as a multiscale “no-regret” solution to SLR. Focusing on the level of coastal
299 municipalities as the main constraint to MR, the decision to end new leases is not motivated
300 by a temporal deadline but instead by a risk threshold that functions as lever against the

301 temporal uncertainties of SLR.

302 Moreover, the draft does not set aside the financial crux of MR. The inclusiveness of
303 ecological restoration as a solution to problems of different spatial scales makes it possible to
304 attract various funding, especially when public spending is restricted. Obtaining money from
305 more sustainable sources than public subsidy alone could also help overcome the reluctance
306 of the private sector to become involved. As a land restoration approach, MR has a legitimate
307 place in land use policies when compensating for flood defence and port projects, as
308 investigated (with mixed success) in England (Dixon et al. 2008). Salt marshes formed
309 through MR comply with the criteria from the European Fisheries Fund, because they act as
310 nurseries for fisheries (Dixon et al. 2008). Funding also exists from schemes to protect the
311 connectivity of an area, provided that MR meets the requirement of achieving a good
312 ecological status. The integration of greenhouse gas removal into the European 2030 climate
313 and energy framework is currently underway, setting the stage for possible financial
314 retribution of carbon stocking by MR.

315

316 DISCUSSION AND CONCLUSIONS

317

318 In our view, the success of MR relies on the inclusion of socio-economic issues in ecological
319 restoration. Coastal municipalities make use of technology (dams, dikes, etc.), anticipate
320 recurring events (marine submersion, storms), and display continual interactions between
321 human and non-human agents on various spatial-temporal scales. Thus, they can be qualified
322 as social-ecological systems, because these processes lead to their establishment, maintenance
323 and reorganization in a form that would otherwise not exist, influencing their capacity to
324 adapt to the effects of SLR (Gunderson & Holling 2002; Sanderson et al. 2016). From this
325 perspective, and because MR is first intended for human groups and initially depends on

326 external economic inputs, it can be considered to be a social-ecological restoration
327 (Fernández-Manjarrés et al. 2018). Importantly, this should not be regarded as the intrusion of
328 social issues into ecological restoration, but on the contrary, as an opportunity for ecological
329 restoration to integrate a utilitarian adaptation to climate change.

330 To support the draft law, a relevant holistic narrative could reveal how interlocking economic,
331 political, and social impediments to local change can be addressed using an imperfect, but
332 promising solution: MR. Panarchy, for instance, combines results on various spatio-temporal
333 scales and from various disciplines (economics, ecology, and others) in a single framework.
334 Unlike hierarchical descriptions of top-down systems, panarchy describes the dynamics of
335 nested natural and social systems that interact in creative, destructive, and evolutionary ways.
336 Each system experience growth and a subsequent stabilization, followed by a collapse phase
337 triggered by an external disturbance (in the case of MR, the interacting subsystems could be
338 those decribed in Table 1); the system can then reorganize and start the cycle again
339 (Gunderson & Holling 2002). Albeit its essentially descriptive approach of social-ecological
340 systems, panarchy is of great help if used in combination with explanatory theories, and has
341 been applied in various research fields including forestry and archeology and other coastal
342 social-ecological systems (Kharrazi et al. 2016; Sanderson et al. 2016).

343 Incentives to switch to MR (i.e., protecting lifes, saving money, restoring ecosystems) are still
344 too weak before the conservative wait-and-see strategy, because of the strong recovery
345 processes and cognitive biases, and because organizations tend to wait for technological
346 developments (Clément et al. 2015; Rey-Valette et al. 2012). Improving the acceptability of
347 MR and ecological restoration as no-regret opportunities is a way to trigger change.

348 Anticipation is the key to transforming the system, and active territorial planning in the
349 French context is a step in this direction (Lurton et al. 2017; Adger et al. 2005; Abel et al.
350 2011). Unlike in the United States, which has market-driven coastal land-planning policies,

351 the cultural preference in France is for territorial projects with a holistic approach, designed
352 with and by the public authorities. This benefits the implementation of MR (Siders 2013;
353 Mineo-Kleiner & Meur-Ferec 2016), supported by the positive outcomes of ecological
354 restoration.

355 These particularities of the current context indicate that ecological restoration offers multiple
356 advantages for MR and that the path to adapting the effects of climate change on coastlines is
357 steep but straight.

358

359 **Acknowledgments:** TF thanks the ENS Lyon for providing a doctoral scholarship, Charente-
360 Maritime inhabitants for valuable discussions, and Guillaume Rieu for logistic support. TF,
361 MT, NF are grateful to two anonymous referees and to the editors for constructive comments.
362 TF, MT, NF thank LabEx BASC for providing a grant (16HGY050). TF, MT, NF have no
363 conflict of interest to declare.

364 **References**

365

- 366 Abel N, Gorddard R, Harman B, Leitch A, Langridge J, Ryan A, Heyenga S (2011) Sea level
367 rise, coastal development and planned retreat: analytical framework, governance principles
368 and an Australian case study. *Environmental Science & Policy* 14:279–288
- 369 Adger WN, Hughes TP, Folke C, Carpenter SR, Rockström J (2005) Social-Ecological
370 Resilience to Coastal Disasters. *Science* 309:1036–1039
- 371 Adger WN, Arnell NW, Tompkins EL (2005) Successful adaptation to climate change across
372 scales. *Global Environmental Change* 15:77–86
- 373 Anziani A (2010) *Xynthia : les leçons d’une catastrophe (rapport d’étape)*. Sénat, Paris
- 374 Carson M, Köhl A, Stammer D, Slangen ABA, Katsman CA, van de Wal RSW, Church J,
375 White N (2016) Coastal sea level changes, observed and projected during the 20th and 21st
376 century. *Climatic Change* 134:269–281
- 377 Cazenave A, Llovel W (2010) Contemporary Sea Level Rise. *Annual Review of Marine*
378 *Science* 2:145–173
- 379 Clément V, Rey-Valette H, Rulleau B (2015) Perceptions on equity and responsibility in
380 coastal zone policies. *Ecological Economics* 119:284–291
- 381 Cour des Comptes (2010) *Les enseignements des inondations de 2010 sur le littoral atlantique*
382 *(Xynthia) et dans le Var*. Cour des Comptes, Paris
- 383 Creed S, Maybank M, Pagny J, Comor M, Deniaud G (2014) *Living with a Changing Coast -*
384 *LiCCo study site report*. European Regional Development Fund, France, United Kingdom
- 385 Dixon M, Morris RKA, Scott CR, Birchenough A, Colclough S (2008) *Managed*
386 *realignment—lessons from Wallasea, UK*. *Proceedings of the Institution of Civil Engineers -*
387 *Maritime Engineering* 161:61–71
- 388 Engle NL (2011) Adaptive capacity and its assessment. *Global Environmental Change*
389 21:647–656
- 390 Feagin RA, Sherman DJ, Grant WE (2005) Coastal erosion, global sea-level rise, and the loss
391 of sand dune plant habitats. *Frontiers in Ecology and the Environment* 3:359–364
- 392 Fernández-Manjarrés JF, Roturier S, Bilhaut A-G (2018) The emergence of the social-
393 ecological restoration concept: Social-ecological restoration concept. *Restoration Ecology*
394 Gunderson LH, Holling CS, eds. (2002) *Panarchy: Understanding Transformations in Human*
395 *and Natural Systems*. Island Press
- 396 Heurtefeux H, Sauboua P, Lanzellotti P, Bichot A (2011) Coastal risk management modes:
397 the managed realignment as a risk conception more integrated. In: *Risk Management in*
398 *Environment, Production and Economy*. InTech.
- 399 Kharrazi A, Fath B, Katzmaier H (2016) *Advancing Empirical Approaches to the Concept of*
400 *Resilience: A Critical Examination of Panarchy, Ecological Information, and Statistical*
401 *Evidence*. *Sustainability* 8:935
- 402 Lambert M-L (2015) *Le recul stratégique : de l’anticipation nécessaire aux innovations*
403 *juridiques*. *VertigO - la revue électronique en sciences de l’environnement*
- 404 Lurton G, Morel-à-l’Huissier P, Bazin T, Cattin J, Menuel G, Perrut B et al. (2017)
405 *Proposition de loi de M. Gilles Lurton portant adaptation des territoires littoraux au*
406 *changement climatique*.
- 407 Mineo-Kleiner L (2017) *L’option de la relocalisation des activités et des biens face aux*
408 *risques côtiers: stratégies et enjeux territoriaux en France et au Québec*. PhD Thesis, Brest
- 409 Mineo-Kleiner L, Meur-Ferec C (2016) *Relocaliser les enjeux exposés aux risques côtiers en*
410 *France : points de vue des acteurs institutionnels*. *VertigO*
- 411 Mossman HL, Davy AJ, Grant A (2012) Does managed coastal realignment create

412 saltmarshes with ‘equivalent biological characteristics’ to natural reference sites? Elphick, C,
413 editor. *Journal of Applied Ecology* 49:1446–1456
414 Pontee NI (2007) Realignment in low-lying coastal areas: UK experiences. *Proceedings of the*
415 *Institution of Civil Engineers - Maritime Engineering* 160:155–166
416 Rey-Valette H, Rulleau B, Balouin Y, Hérivaux C (2016) Enjeux, valeurs des plages et
417 adaptation des territoires littoraux à la submersion marine. *Économie rurale* 49–65
418 Rey-Valette H, Rulleau B, Meur-Férec C, Flanquart H, Hellequin A-P, Sourisseau E (2012)
419 Les plages du littoral languedocien face au risque de submersion : définir des politiques de
420 gestion tenant compte de la perception des usagers. *Géographie, économie, société* 14:369–
421 391
422 Rocle N, Salles D (2017) ‘Pioneers but not guinea pigs’: experimenting with climate change
423 adaptation in French coastal areas. *Policy Sciences*
424 Sanderson EW, Solecki WD, Waldman JR, Parris A (2016) *Prospects for Resilience: Insights*
425 *from New York City’s Jamaica Bay*. Island Press
426 Siders A (2013) *Managed Coastal Retreat: A Legal Handbook on Shifting Development*
427 *Away from Vulnerable Areas*. Columbia Law School Public Law & Legal Theory Working
428 Paper Group, January 10
429 Temmerman S, Meire P, Bouma TJ, Herman PMJ, Ysebaert T, de Vriend HJ (2013)
430 Ecosystem-based coastal defence in the face of global change. *Nature* 504:79–83
431 Touili N, Baztan J, Vanderlinden J-P, Kane IO, Diaz-Simal P, Pietrantoni L (2014) Public
432 perception of engineering-based coastal flooding and erosion risk mitigation options: Lessons
433 from three European coastal settings. *Coastal Engineering* 87:205–209
434 Van Der Maarel E (2003) Some remarks on the functions of European coastal ecosystems.
435 *Phytocoenologia* 33:187–202
436 Vinchon C, Baron-Yelles N, Berthelie E, Hérivaux C, Lecacheux S, Meur-Férec C, Pedreros
437 R, Rey-Valette H, Rulleau B (2011) MISEEVA : Set up of a transdisciplinary approach to
438 assess vulnerability of the coastal zone to marine inundation at regional and local scale,
439 within a global change context. In: *Littoral 2010 – Adapting to Global Change at the Coast:*
440 *Leadership, Innovation, and Investment*. EDP Sciences p. 11003.
441 Wong PP, Losada IJ, Gattuso J-P, Hinkel J, Khattabi A, McInnes KL, Saito Y, Sallenger A
442 (2014) Coastal systems and low-lying areas. In: *Climate Change 2014: Impacts, Adaptation,*
443 *and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to*
444 *the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Field, C.B.,
445 V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi,
446 Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R.
447 Mastrandrea, and L.L. White, Cambridge, United Kingdom and New York, USA pp. 361–409.
448
449
450

451 **Tables**

452 Table 1

453 Current social-ecological environments of French coastal municipalities with their spatial and
 454 temporal scales. Characteristics and scales inspired by Wong et al. (2014), Feagin et al.
 455 (2005), Carson et al. (2016), and Mineo-Kleiner (2017).

456

	Beach sediment cells	Coastal municipalities	Management practice	Ocean systems
Nature of the system	Biophysical transport of sediments	Social and economic development strategies in municipalities with seafront access	Mental representations of human interventions regarding ecosystems	Climatic cycles of oceans
Spatial scale	1–10 km	5–20 km	France	Planetary
Temporal extent under current functioning	Years	Municipal mandate (6 years)	10–50 years	Geological times, 10 ⁴ –10 ⁶ years
Indicator of change	Accumulation of sediments	Population growth and seasonal affluence of visitors	Prevalence of knowledge and representations of management practices	Sea level
Indicator of resilience	Seasonal return of beach vegetation	Return rate of population and visitors after disturbance	Ability of the current values to keep leading coastal policies	Latence time needed to return to pre-industrial periodic oscillations of geological climate
Former state of the system	Balance between erosion and sediment accumulation	Plans for tourism development, population growth, gradual institutionalization of conflict resolution through property rights or coastal laws	Command and control	Pre-industrial sea level
Current state of the system	Coastline retreat	Coastal armoring, tourist and transportation saturation, with degradation of tourist resorts by winter storms	Static perception of coastline land use (no influence of environmental changes) with conflicting rules and consolidated institutions	Sea-level rise
State of the system under managed retreat	Dune and salt marsh revegetation	Managed retreat economy: beach tourism, outdoor recreative coastal usage	Adaptive management of climate change, “monitor and adapt” approach	Uncertainties, but projected higher sea levels and disrupted marine streams

457