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1 **The calm before the storm: How climate change drives forestry evolutions**

2

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11

12

¹ TF and AC collected data; TF conceived, designed, and wrote the paper; MT and NF edited the manuscript.

13 **Highlights**

- 14 - Climate change weakly modifies forestry compared to techno-economic evolutions.
15 - Most adaptations focus on technical operations and ignore organizational changes.
16 - Ecological processes are instrumental and applied at the forest stand scale.

17

18 **Abstract**

19 Adapting forest management to climate change is a key issue, as forests are crucial for mitigation
20 policies and the provision of many ecosystem services. Understanding the magnitude of the progress
21 made in this respect can help shape further adaptation developments and avoid the putative
22 maladaptive side effects of forest management evolutions. Here, we aim to bridge the knowledge gap
23 of adaptation implementation in French forests. To stay as close as possible to concrete changes, we
24 conducted semi-structured interviews with foresters in two study areas that differed in the intensity of
25 their forest management approaches. Our findings highlight unprecedented aspects of adaptations: (i)
26 adaptation focuses on productive ecosystem services at the expense of other essential services such as
27 water supply or natural habitats; (ii) adaptations rely on technical changes in forest management and
28 do not deal with climate impacts through organizational or economic tools; and (iii) envisaging
29 ecological processes through adaptations is instrumental and limited to small spatial and temporal
30 scales. Our results also extend the existing body of knowledge to the framework of forest
31 management: (i) climate change is not the main driver of forestry changes; (ii) extreme events are
32 windows of opportunity to stimulate adaptive changes; and (iii) proactive adaptation to unexperienced
33 hazards is very weak. We argue that to be as effective as possible, climate change adaptation in
34 forestry should implement complementary organizational and economic changes in addition to the
35 necessary technical evolutions.

36

37 **Keywords:** Adaptation, climate change, forest, social-ecological, biodiversity, France

38

39 1. Introduction

40

41 Forestry is the art of creating, restoring, or using forested areas in order to conserve them and
42 benefit from their goods and services. By its very essence, forestry has undergone many evolutions
43 relating to technical (e.g., mechanization of felling), social (e.g., increased demand for sustainable
44 ecosystem management), and economic developments (e.g., changes in charcoal production) (MCPFE
45 1993; Mather 2001; Bolte et al. 2009). To keep up with these developments, foresters have developed
46 different practices, often distinguished by the intensity of their management or the type of ecosystem
47 goods and services (ES) favored (Duncker et al. 2012). Despite their wide variety, silvicultural
48 treatments were implicitly considered to be climatically stable (to some extent) until the changes of the
49 last few centuries (Millar and Stephenson 2015). In other words, climate change now calls into
50 question forestry principles such as the choice of species suited to local biogeographical factors (Bolte
51 et al. 2009).

52 Forest landholders and managers must now renew their forestry paradigms in order to tackle
53 the intensification of stress factors brought about by climate change. In Europe, a decrease in forest
54 health and productivity is expected to result from rarer cold extremes and more frequent and severe
55 heat waves, followed by pathogen attacks (Ciais et al. 2005; Bréda et al. 2006). Biotic threats such as
56 introduced pests (e.g., pine wood nematode *Bursaphelenchus xylophilus*) and spontaneously invasive
57 species (e.g., ash fungi *Chalara fraxinea*) have already shown their huge potential for damage (Bakys
58 et al. 2009; Futai 2013). Moreover, interactions between these many climate-related stress factors as
59 well as other issues such as air and soil pollution increase concerns about the future of forest
60 management (Paoletti et al. 2007; Keenan 2015). The outlook of climate change for temperate forests
61 is somber, and even the beneficial side effects of climate warming in terms of increased forest growth
62 are now moderated by recent research on the importance of vapor pressure deficit (Bolte et al. 2009;
63 Yuan et al. 2019).

64 In this context, foresters should already account for adaptations to climate change, because of
65 the large timescale of forest development. Adaptive processes occur at different levels when climate
66 change does not lead to local forest decline or extinction. At the individual tree level, phenotypic
67 plasticity and phenological changes can contribute to the tree's acclimatization (Aitken et al. 2008). At
68 the population level, evolutive processes or migration toward suitable sites can occur (Noss 2001;
69 Alberto et al. 2013; Bussotti et al. 2015). Ultimately, forest managers can set strategies to deal with
70 climate change and increase the resilience of forest communities (Millar et al. 2007; Keenan 2015).

71 In line with the need to adapt, an abundant body of literature now confirms how “climate-
72 proof” paradigms of forest management have arisen such as adaptive management (Linder 2000; Noss
73 2001; Bolte et al. 2009) and the consideration of uncertainties by diversifying silvicultural practices
74 and objectives (Keenan 2015; Augustynczyk et al. 2019). However, in comparison, very little research
75 has explored how foresters currently handle the impacts and uncertainties of climate change in the

76 field (Kolström et al. 2011; Van Gameren 2014; Nelson et al. 2016). This is of the highest importance,
77 because concrete changes drive forest ecological trajectories, and feedback from the field can help to
78 improve public policies related to forest management (Brockerhoff et al. 2017; Williamson et al.
79 2019).

80 Therefore, the rationale of this study is to describe the field adaptations and the drivers that
81 could have been implemented in the temperate forest sector. It draws on interviews with French forest
82 managers (owners, private forest advisors, or public practitioners). Three reasons motivate the choice
83 of this country as a study case. First, the country has a vast forested area (169,000 km², the third
84 largest volume in Europe; IFN 2018). Second, its timber industry is economically important for
85 employment, which influences public policies for its adaptation to climate change (MAAF 2017).
86 Third, France is expected to experience the impacts of climate change in all its forest ecosystems
87 (ONERC 2015).

88 The paper is organized as follows. After presenting the methodological aspects of the research,
89 we identify the importance attached to climate change adaptation in the evolution of forestry practices.
90 Then, we analyze the objectives and means of adaptations. Finally, we investigate how foresters
91 envisage the relations between adaptation and ecological processes.

92

93 **2. Materials and methods**

94

95 *2.1. Study cases*

96

97 Forest management couples human and natural systems in interaction and can therefore be
98 considered to be a social-ecological system (Liu et al. 2007). From this perspective, social, economic,
99 and ecological criteria oriented the selection of our study areas so as to retain French sites with
100 opposing approaches to forest management in terms of objectives and technical interventions.

101 The “Vosges du Nord” (hereafter “Vosges”) is a sub-mountainous temperate zone lying at the
102 northeastern border separating France and Germany. Dating back centuries (Jéhin 2005), this forest
103 now features a species mixture dominated by European beeches (*Fagus sylvatica*) and oaks (*Quercus*
104 *robur* and *Quercus petraea*). This mixture is said to be a natural forest vegetation, while managed
105 forests significantly admix conifers and, to some extent, other broadleaved species (IFN 2018). Forest
106 management culturally favors semi-natural processes such as natural regeneration, multi-storied stand
107 structure, and long-term tree development, similarly to what happens in the nearby German region of
108 Baden-Württemberg (Duncker et al. 2012). Private ownership represents 15% of the total surface, with
109 most forests being the property of municipalities or the French state.

110 The second study area, the “Landes de Gascogne” (hereafter “Landes”), is a human-made
111 forest in southwestern France. After two centuries of intensive management, it expanded by draining
112 the former marshlands (Deuffic et al. 2010). Nowadays, the monoculture of maritime pines (*Pinus*

113 *pinaster*) requires the plowing of soil, the planting of selected seedlings, and the clearcutting of trees
114 between their 30th and 40th year. Private ownership represents 95% of the total surface, making the
115 Landes forest one of the largest privately owned forests in Europe (Deuffic et al. 2010).

116 Throughout the article, interview samples are referred to by their anonymization number
117 (Appendix 1). They begin with “V” or “L” in reference to the Vosges or Landes region, respectively.
118 When present, the bracketed text includes indications previously given by the interviewee.

119 The relevance of the contrasting characteristics of the study areas was later confirmed in many
120 interviews. A Landes interviewee thus stated: “It is not the factory that adapts to the forest, it’s the
121 opposite; it is the forest that adapts to the factory” (L12), while in the Vosges, another interviewee
122 explained that “The sawmills have to adapt to what the forest produces; the forest does not adapt to the
123 sawmills” (V13).

124

125 *2.2. Data collection*

126

127 To evaluate field adaptations to climate change, we carried out 27 individual semi-structured
128 and open-ended interviews during June and July 2017. Interviews were quasi-equally distributed
129 between the Vosges (n=13) and the Landes (n=14). Interviewees were selected to cover the range of
130 forest stakeholders intervening on management decisions (Appendix 1). For private forests, we
131 interviewed private owners and professional forest advisors; for state forests, forest managers from the
132 National Forests Office (NFO; “Office National des Forêts” in French), the public agency responsible
133 for their management; and for municipal forests, local officials and their advisors from the NFO. To
134 benefit from the perspective of the timber industry, we completed the panel with interviews of
135 professionals from forestry cooperatives (Appendix 1).

136 Each interview followed the same pattern: (i) a description of forestry practices used by the
137 interviewee; (ii) a depiction of their evolution over time; and (iii) the interviewee’s viewpoint on the
138 impediments and assets to reaching the desired silvicultural practices. If the interviewee did not
139 spontaneously mention recent climatic events, we asked for his reactions to the recent windstorms
140 known as Lothar (in 1999) and Martin (in 2003).

141 Every interview was recorded, fully transcribed, and qualitatively analyzed. Audio tracks and
142 written transcriptions were analyzed using *Sonal*, an encoder software conducting audio-textual
143 synchronization. *Sonal* allows for the identification of thematic and statistic discourse studies such as
144 topic occurrences and/or co-occurrences (e.g., “logging practices” and/or “forest uses”) (Nicolas
145 2013).

146

147 *2.3. Characterization of evolutions in forest management*

148

149 Evolutions were identified by isolating interview samples that mentioned one or several
150 changes made to forest management: for example, “In the past, there weren’t all these big machines”
151 (V10). We specifically labeled as “adaptation” the evolutions triggered by the direct impacts of
152 climate change: for example, “The next generation [of maritime pines] is under selection and should
153 be more oriented toward... How to say it? Toward the consequences of global warming and a better
154 resistance to drought” (L9). “Adaptations” did not include evolutions relating to the indirect impacts
155 of climate change such as developing mitigation policies: “Harvesting the [forest] growth to supply
156 the wood-energy sector, which will then replace hydrocarbons and nuclear energy – this is the French
157 energy policy” (V7).

158 Using discourse analysis, two categories were then assessed for the drivers of adaptations. On
159 the one hand, we explored goal-directed drivers, which are the adaptations focused on ES (timber
160 production, water purification, hunting, carbon storage, etc.). On the other hand, we investigated risk-
161 directed drivers, namely specific climate hazards to be prevented (storms, droughts, pathogens, etc.).
162 Adaptations driven by risk aversion were also distinguished depending on whether they were already
163 implemented or not. No consideration of the relative success of these different adaptations were made.
164 We considered that our study is too premature for an *ex-post* evaluation, and we avoided any value
165 judgment, as the definition of successful adaptation is personal and therefore subjective.

166 Analyses of adaptations were completed by a characterization of their management intensity
167 based Duncker et al. (2012) and Biber et al. (2015). This qualified whether the adaptive approaches
168 drew on the ecological processes of forest growth and development (e.g., close-to-nature silviculture)
169 or on a high degree of anthropization (e.g., artificial maintenance of a tree population through
170 plantation despite declines following decreasing rainfalls) (Gamborg and Larsen 2003; Pramova et al.
171 2012; Brang et al. 2014). To gain insight into this issue, we also relied on the language elements found
172 in the interviews, which related to the ecological processes such as “biodiversity,” “nature,”
173 “sustainable management,” “wildlife,” or “fauna and flora.”

174

175 **3. Forestry evolutions not driven by climate change adaptations**

176

177 *3.1. Mainstreaming of forest management in the timber industry*

178

179 The last three decades have brought about common changes to the Vosges and Landes
180 regions. All these evolutions have converged in the reinforcement of linkages between upstream and
181 downstream forest-based activities.

182 Upstream activities include proper forestry operations such as the choice of forest regeneration
183 and logging practices. Mechanization was by far the most cited evolution (9 interviews), with a more
184 frequent use of harvesting machines and more powerful machines, as illustrated by interviewee L5:
185 “There is a clear evolution. It is the acceleration of mechanization, of its intensity, and... It is the

186 increase in the power of the machines.” The prevailing place of mechanization is a common evolution
187 in forestry, which is also found in other national contexts (Heinimann 2007; Marchi et al. 2018).

188 On the downstream side of the timber industry – wood processing and organization between
189 stakeholders of the forest sector –, evolutions mostly related to the industrialization and
190 standardization of the production. Economic competition between sawmills spurred the transition from
191 a network of small industrial units to fewer and larger plants: “It has already been 10 years, so
192 unfortunately it’s a long-term trend that there are fewer and fewer [wood] processers” (L9). Seven
193 interviewees observed that this growing industrial concentration went hand-in-hand with the
194 replacement of timber auction sales by supply contracts. They pointed out that the aim is to secure
195 timber-based resources for forest landowners and stabilize the supply of sawmill and paper industries.
196 In addition to these industrialization processes, the standardization of forestry practices was fostered
197 by the social demand for the certification of sustainable logging such as PEFC or FSC, a change once
198 again observed in both the Landes (L8) and the Vosges (V5).

199 We argue that most forestry evolutions followed 1999, a critical year because of the Lothar
200 windstorm (MTES 2017), with this *tabula rasa* being used by the forest industry to build up a “shock
201 doctrine” (Klein 2008). As underlined by interviewee L2, “Before ‘99, timber exploitation was done
202 by hand by lumbermen, and since around ‘99, there has been all this mechanization... Often the
203 industries subsidized the firms to invest in these machines.” Subsequent catastrophes are frequently
204 described as windows of opportunity to introduce innovations (Abel et al. 2006), as they provided the
205 timber industry with a chance to ensure a business built on sowing, cultivation, and logging machines.

206

207 3.2. Climate change adaptation: Reaction first

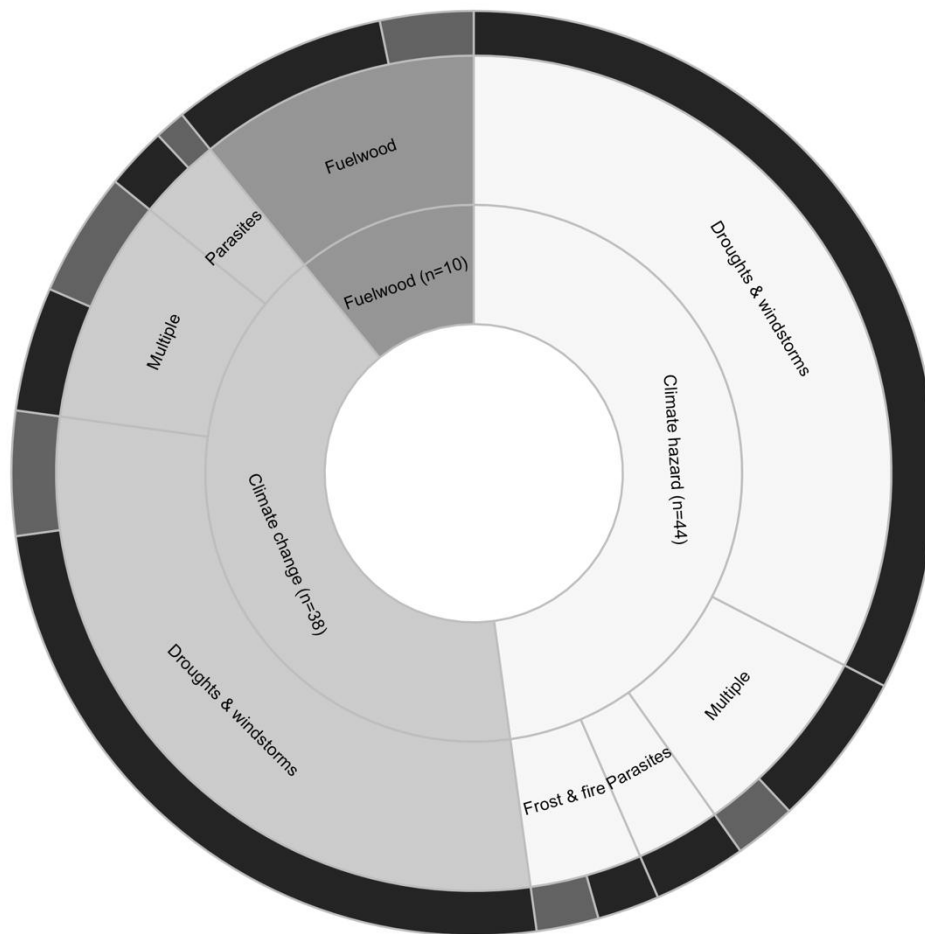
208

209 In total, we identified 82 samples of interviews from 24 different interviewees (12 from the
210 Landes and 12 from the Vosges) mentioning an evolution of forestry practices due to climatic risks.
211 Even if they mentioned a climatic *risk*, 44 evolutions of forestry practices made no clear mention of
212 their link to climate *change* (Fig. 1), so they were not viewed as adaptations to climate change.

213 Overall, 38 evolutions of forest management distinctly responded to the intensification of
214 hazards because of climate change (Fig. 2). Among the 38 adaptations mentioned, 27 related to the
215 hazards of severe droughts and windstorms, which worried many interviewees, as depicted by
216 interviewees L4: “In this area, as soon as the wind starts blowing, people don’t sleep anymore, you
217 know” and V2: “For this time of the year, not much water is flowing... There isn’t enough water
218 here.”

219 Among the 14 foresters who associated these 27 adaptations to droughts and storms, 9 had
220 already changed their forest management in order to account for such hazards, while another 2 had
221 launched experiments on technical adaptations such as assisted migration. The 11 other adaptations to
222 climate change mentioned by 6 different foresters related to a mixture of different sources of stress

223 (parasites, phenological changes, etc.) or parasite attacks (n=3) (Fig. 1) and were partially operational
224 in the field.
225



226

227

228 **Figure 1. Climate-related drivers of forestry evolutions and their implementation.** Interview
 229 samples labeled as “climate hazards” differ from those mentioning “climate change,” as the evolution
 230 of forestry practices does not result from a change in the climate. The rising demand for fuelwood due
 231 to public policies on mitigation was the only indirect driver of forestry evolutions found in the
 232 interviews. The external ring indicates the implementation status of a forestry evolution. Please note
 233 that the counts refer to the number of interview samples and not to the number of interviewees, as one
 234 interview potentially contains several samples relating to an evolution of forestry practices.

235

	1. Passive	2. Low	3. Medium	4. High	5. Intensive
A. Naturalness of tree species composition		Increased species mix Native species Change in seedling origin	Favoring drought-resistant species	Assisted migration	
B. Tree improvement			Drought criterion added to tree breeding		
C. Regeneration		Change seedling origin	Natural selection		
D. Machine use					
E. Soil operations				Subsoiling	
F. Use of chemicals			Pesticide treatment		
G. Tree removal	None - Free evolution				
H. Silvicultural system		Shelterwood irregularization	Stronger thinning	Fewer clearcuts	
I. Temporality				Shortened rotations	

Number of interviewees mentioning ≥ 1 adaptations

①

① ⑥

⑧

③ ②

Landes
Vosges

236

237

238 **Figure 2. Climate change adaptations rely on technical operations at different decision stages of**
 239 **forest management.**

240 *Columns:* the five forest management approaches are taken from Duncker et al. (2012) and ranked by
 241 the intensity of forest management. “Passive”: unmanaged forest nature reserve; “Low”: close-to-
 242 nature forestry; “Medium”: multifunctional forestry; “High”: intensive even-aged forestry;
 243 “Intensive”: short rotation forestry. *Lines:* adaptive changes in the major decisions involved in forest
 244 management, inspired by Duncker et al. (2012). D: progress of machine usage was evoked, but not in
 245 relation to climate change. *Bottom:* Vosges interviewees were overrepresented among those speaking
 246 of adapting to climate change.

247

248 This situation is the paragon of reactive adaptations, defined by Adger et al. (2005) as
249 “adjustments in ecological, social, or economic systems in response to observed or expected changes
250 in climatic stimuli and their effects.” As found in the literature, the experience of a natural disaster
251 enhances risk perception (Berrang-Ford et al. 2011; Rey-Valette et al. 2012; Keskitalo et al. 2016). In
252 line with this, interviewees generally evoked the exceptional heat waves experienced in 2003 as well
253 as the devastating Lothar and Martin windstorms (in 1999 and 2009, respectively). The infrequent
254 mention and operational implementation of the other repercussions of climate change can be qualified
255 as a wait-and-see attitude, an example of which is seen with forest advisor V1: “There are no easy
256 answers to give to private owners, but what’s important today is to limit damage.” We thus argue that
257 focusing on past hazards could be detrimental to a proactive adaptation to other impacts (e.g.,
258 development of parasite attacks, phenological changes) (Engle 2011).

259 Compared to the 82 changes in forestry practices driven by climate risks, the indirect driver of
260 the rising demand for fuelwood, triggered by public policies in favor of mitigation, was mentioned 10
261 times (Fig. 1): 9 interviewees cited their interest in supplying fuelwood to diversify their income
262 sources, while 7 reported a prior change in this direction such as slash and/or stump removal. This can
263 be considered to be a weak modification of forestry practices, although it indicates how the indirect
264 impacts of climate change can have important consequences in the field. It also raises the issue of how
265 climate change modifies the prioritization of ES resulting from forest management.

266

267 **4. A narrow focus of adaptation on timber production and technical changes**

268

269 *4.1. Adaptation: Change of practices, continuity of objectives*

270

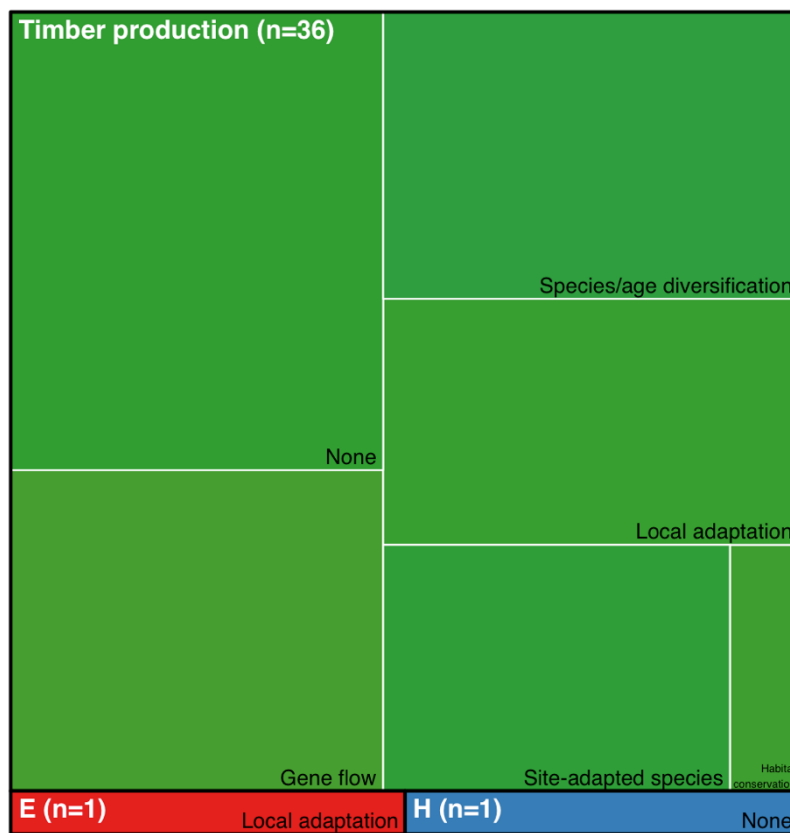
271 A complementary perspective on climate change adaptations is found when looking at the type
272 of ES favored. Among the 38 interview samples referring to adaptation, 36 focused on timber
273 production (Fig. 3). Only one mentioned biodiversity conservation (V8 interviewee wished to leave up
274 to 10% of the forested area in free evolution), while another related to sanitary issues for local
275 populations: “Climate regulation [of the processionary moth] barely exists, and besides, there are all
276 the consequences on parasitoids, viruses, bacillus” (V7).

277 This finding was expected, as productive ES contribute the most to forest-based revenues
278 (Cinotti 2003), as stated by interviewee V13 regarding water eputation and carbon storage: “The
279 owner only makes money from timber sales, being about 90% of revenues, with only 10% coming
280 from hunting leases. Up to now, what’s left is for free, a gift to society!” Adapting for timber
281 production is of great interest, as it encourages the use of wood as a renewable and potentially
282 sustainable source of material and energy (Baral 2004). However, losing sight of non-productive ES in
283 climate change adaptation could have dramatic effects, as climate change also affects forest-based
284 water supply (Ford et al. 2011) and local or regional climate cooling (Ellison et al. 2017). This could

285 have adverse effects on forest leisure services (Gray et al. 2009) or biodiversity functioning in forest
 286 ES (Brockerhoff et al. 2017).

287 The limited vision of adaptation regarding timber production is also shown by the lack of
 288 “soft” evolutions of forestry (Fig. 2). Only 3 interviewees alluded to adaptations not related to
 289 technical changes. These non-technical adaptations included the development of an insurance system
 290 against frost (L10), the launch of mycosilviculture (Savoie and Largeteau 2011) as a way to balance
 291 forest incomes threatened by climate change (L7), and the creation of stories about forest and climate
 292 hazards to monitor climate change among the local population. These three adaptations were not
 293 planned despite their potential to diversify forest management at a scale other than forestry practices
 294 alone, as highlighted in forest economics literature (Keenan 2015; Brunette et al. 2017).

295



296
 297

298 **Figure 3. Forestry adaptations to climate change focus on productive ecosystem goods and**
 299 **services.** In a treemap, the size of the cells is proportional to their importance. In white, the objectives
 300 of climate change adaptations, as expressed by the interviewees: E = ecological conservation
 301 (conservation of natural habitats in an unmanaged area); H = human health (limiting the sanitary
 302 effects of processionary moth on hikers). When they were considered, ecological dynamics and
 303 biodiversity were quasi-systematically seen in a utilitarian light. Most interviewees relied on the
 304 complementary effect caused by diversifying species composition through, for instance, the
 305 introduction of exogenous populations or species or the selective adaptation to local climate
 306 conditions.

307
308
309

4.2. *Adapters differ in terms of the intensity of management*

310 The abovementioned focus on technical adaptations has been identified in other European
311 situations (Van Gameren 2014). Interestingly, the 15 different interviewees who spontaneously
312 addressed adaptation (4 from the Landes and 11 from the Vosges) presented a strong differentiation in
313 the way in which they envisaged adaptations based on their native regions.

314 In the Landes, all but two interviewees (L3 and L5, interested in close-to-nature forestry) had
315 faith in forestry progress in order to overcome the impacts of climate change. After the two
316 windstorms, they witnessed the resilience of the monoculture of maritime pines with increased
317 interventionist operations (Fig. 2). Indeed, it was mostly after the Lothar damage that regeneration by
318 planting superseded seeding and natural regeneration, with the rocketing of mechanization and
319 increase in tree breeding. This “return to normalcy” by the intensification of the former forestry
320 system is characteristic of this region, which has historically used anthropization processes (saltmarsh
321 draining, firebreak grids, etc.) to adjust to local biogeographical constraints (Deuffic et al. 2010).
322 However, strong technical framing that focuses on only a few environmental variables might lead to
323 detrimental maladaptation. As an example from the Landes, a forest landowner detailed how he
324 deepened subsoiling to facilitate water pumping by the roots of maritime pines. Subsoiling caused
325 undesired draining of the stand and lesser resistance to windstorms. During a windthrow, instead of
326 falling at once to the ground, the trees would break into two pieces because of their deeper rooting,
327 thus limiting the subsequent use of harvest machines.

328 The Vosges “adapters” were less dependent on intensive forestry practices such as planting,
329 fertilization, and plowing in their silvicultural systems. In the adaptations mentioned, they mostly
330 resorted to ecological processes such as local acclimatization and adaptation to recurrent droughts, or
331 to the complementary effects (e.g., overyielding, parasite dilution effect) of mixed species stands.
332 While this approach is closer to a bet-hedging strategy through species diversification (or “insurance
333 hypothesis”; (Yachi and Loreau 1999)), it might also lead to maladaptation because of the lag between
334 rapid climate change and lengthy forest dynamics (Aitken et al. 2008).

335

4.3. *Foresters are between a rock and a hard place*

337 A very striking feature of the discourses of “adapters” was the lack of shared understanding on
338 how to efficiently counter the impacts of climate change. Many foresters expressed a feeling of
339 powerlessness to deal with the “injunction to adapt,” given the current economic constraints: “The
340 problem today is that we have no information and we cannot afford to wait 30 years to make
341 decisions” (V7).

342 In this highly uncertain context of climate change, foresters do their best to prepare to future
343 climate hazards, but they especially favor these adaptations addressing their current concerns. This

344 fuzziness led to the use of technical arguments in order to legitimate their own preference for a
345 particular kind of forest management, as phrased by interviewee V1 with regard to shortened rotations:
346 “Under the pretext of climate change, the timber industry could sneak in.” In the case of windstorms,
347 for instance, the Vosges interviewees insisted on irregular shelterwood and species mixtures, thus
348 rejecting even-aged silviculture: “The cathedral forest, it’s over! It is way too vulnerable to
349 windstorms” (V5). However, in the Landes, many interviewees were convinced of the opposite:
350 “There’s not many solutions. We need an even-aged treatment, where we control the harvest, so that
351 we have thick stems allowing for the individual stability” (L9). Other examples of technical
352 discussions exist such as the use of exogenous species to cope with parasite attacks and changes in the
353 thinning intensity. Arguments in favor of more biodiverse forests were also used in discourses on
354 adaptation to climate change, especially by the interviewees most attached to ecological conservation.

355

356 **5. Ecological processes are instrumental to adapt at small spatiotemporal scales**

357

358 Almost all the interviewees regarded ecological processes as the utilitarian tools to adapt,
359 whatever their preference for forestry evolutions in terms of the intensity of management. Some tried
360 to set “safeguard” measures to reduce the potential deleterious effects of adaptive changes on these
361 ecological processes.

362

363 *5.1. An instrumental vision of ecological processes in adaptive changes*

364

365 Ecological conservation was not the predominant matter of concern for interviewees when modifying
366 their forest management (Fig. 2). More specifically, discourses on “biodiversity,” “nature,” and “the
367 environment” almost always accompanied considerations of other ES, mostly timber production, but
368 also forest scenery or hunting: “These is spontaneous growth, with biodiversity being much more
369 important than in an even-aged forest regularly managed by a state forester. So here it’s the habitat for
370 game” (V12).

371 The consideration of ecological processes as a tool for forestry and biodiversity conservation
372 as a by-product of instrumental evolutions of forestry was also true in the discourses on adaptation to
373 climate change. Biodiversity was often cited as a key to cope with climate change at the genetic level
374 (V6: “It’s supposed that the genetic pool is strong enough to absorb major shocks”), within stands (L5:
375 “In my opinion, the more complex the whole is, the more resistant it is to hazards, to accidents, to
376 parasites. So I want it to be complex”), or at a wider regional scale (V10: “I think that [Douglas fir] is
377 the species that will resist if problems occur, and so it’s good that a few are spread all over”) (Fig. 2).

378 However, it is not because climate change adaptations prioritize the intrinsic value of
379 biodiversity and natural habitats that they necessarily involve a higher intensity of forest management
380 (Fig. 2). Even if it was not prevalent in the interviews, the growing recognition of ecosystem-based

381 adaptation to climate change resonates with the development of close-to-nature forestry (Gamborg and
382 Larsen 2003; Naumann et al. 2011). Two interviewees, both prominent members of the French
383 ProSilva branch (ProSilva 2017), stressed the long-term ecological and economic resilience to climate
384 change provided by irregular shelterwood, selective thinning, and species mixture: “A diverse system
385 is more stable, as it lasts better than a ‘house of cards’ system” (V13). It must also be said that
386 intensive management should not be banned from adaptations aimed at ecological conservation: it can
387 be a prerequisite for operations focused on ecological restorations or rehabilitation (e.g., Fouqueray et
388 al. 2018), all the more in a rapidly changing context (Aitken et al. 2008).

389

390 *5.2. Impacts of climate change adaptations on ecological processes*

391

392 Whatever their level of management intensity, many of the adaptations cited in the interviews
393 were not easily reversible or required great effort and time. Therefore, questions arise concerning their
394 impact on forest ecological processes in the medium and long term, as well as the basic principles of
395 sustainable forestry that can be called on to assess them (Lindenmayer et al. 2006; Brang et al. 2014).

396 Adaptation to climate change could increase the standardization of forest ecosystems by
397 neglecting mixtures of tree species and/or ages and skipping forest successional stages. An example is
398 assisted migration: while species translocation or species introduction can accelerate gene flow
399 (Sansilvestri et al. 2015), they should not ignore key ecological features such as extended phenotypes
400 (Frascaria-Lacoste and Fernández-Manjarrés 2012) or bypass the monitoring of potentially unwanted
401 genotypes or invasive species (Lefèvre et al. 2014).

402 Adaptation by shortening rotations and harvesting more biomass could threaten the
403 maintenance of natural habitats and lead to intensified forest use. Rotation shortening diminishes the
404 number of cavity trees (Fan et al. 2004), but compensatory measures exist to balance its consequences:
405 “We have old-growth tree plots, a network of plots that we develop across the territory, which is
406 supposed to compensate the fact that we, as foresters, cut the trees before they die” (V7). Concerns
407 were raised regarding aboveground habitats, but almost none of the interviewees addressed soil
408 ecology. Soil processes are affected by discarding broadleaved species in adaptations to climate
409 change (in the Landes) and by harvesting tree tips, slash, and stumps to respond to the rising demand
410 for fuelwood. Such adaptations do not account for repercussions on soil fauna, which could have long-
411 term effects on soil fertility and ripple effects on forest (Walmsley and Godbold 2010; Henneron
412 2014). However, the intensification of forest use is to be balanced by the low and long-term return on
413 investment following forestry operations (e.g., storage platforms), which tends to deter private owners
414 from intensifying tree removal: “I’m 70 years old now, so I don’t want to make an investment that
415 would be profitable in perhaps 50 years” (V11).

416 With respect to ecological processes, the most noticeable output of the interviewees was the
417 lack of focus on the landscape scale. Almost all adaptations were applied to the tree or stand level,

418 whereas ecological and evolutive processes occur at much wider spatial scales. This discrepancy was
419 obvious in the Landes, with all but two interviewees considering the role of biodiversity to be an
420 external variable of forestry and adaptation. In this forest heavily constrained by soil conditions and
421 economic pressure, the changes in practices relating to biodiversity were confined to the borders
422 between forest stands: “We know that broadleaved trees resist better [to windstorms], that they have
423 advantages in terms of humus, parasite resistance, etc. So yes, we’re pushing ourselves to create
424 wooded corridors along roads and ditches” (L11).

425 The interviewees most concerned with sustainable forest management were mostly municipal
426 officials and regional representatives from the Ministry of the Environment, who felt committed to
427 multifunctional forestry for multiple ES at the same time. They also worried about a lack of support
428 from public policies that, in their eyes, did not have a strong endorsement regarding sustainable
429 practices. As a matter of fact, it is only in the last few years that the national plan for adaptation to
430 climate change prompted the development of nature reserves and the consideration of biodiversity
431 issues (ONERC 2017).

432

433 **6. Conclusion**

434

435 This article hints that adaptation to climate change is not a major driver of French forestry
436 changes either in the direct management of forest ecosystems or in the organization of how forest-
437 based ES are used and supplied. Among the many technical, organizational, and economic adaptations
438 found in the literature, the interviews showed that only some of them were implemented in the Vosges
439 and Landes regions. In the two French study cases, implementation focused on technical changes
440 fostering timber production and considered ecological processes to be instrumental features of
441 forestry, a finding similar to what has been observed in the Swedish, Australian or Canadian forest
442 sectors (Keskitalo et al. 2016; Keenan 2017; Williamson et al. 2019).

443 Methodological choices aimed to reflect the intrinsic complexity of forested socio-ecosystems,
444 envisaging forestry as a complex system embedded in an ever-changing world. It should be reiterated
445 that the two study cases were selected because of their opposing forest management approaches in
446 terms of their intensity of management. Complementary research is ongoing (personal
447 communication) in order to fill the knowledge gap for adaptive changes occurring in intermediary
448 forest approaches from other regions.

449 Nevertheless, our findings raise two concerns in terms of how foresters currently apply
450 adaptation decisions. First, we underlined how foresters displayed a preference for slowly reversible
451 changes and how they discarded landscape ecological processes in their management changes. This
452 can lead to adaptations suitable for a specific time and place at the expense of adaptations for the
453 future or at another spatial scale (Carpenter et al. 2001). In a context of high uncertainties, no-regrets
454 and reversible solutions are a way to avoid potential collateral damages to the current adaptations,

455 either later or elsewhere. Ecosystem-based adaptations and nature-based solutions have been depicted
456 as emerging adaptation mechanisms that account for these limitations of the current adaptation (Balian
457 et al. 2014; Eggermont et al. 2015). Second, the lack of regional concertation around adaptations
458 (especially in private forests) hinders the elaboration of complementary regional approaches that could
459 integrate ecological issues. If set up, concertation considering social logics could support learning
460 exchanges by distributing experimental stands at the regional scale (Andersson and Keskitalo 2018). It
461 could also be a way to tackle other forest hazards associated with climate change and amplify them
462 such as the overload of wild grazers.

463 Faced with the uncertainty and urgency of climate change, we argue that the time has now
464 come to invest more time. We acknowledge the crucial role of technical changes in forestry and the
465 need to upgrade their design at a wider spatial scale (Williamson et al. 2019). However, a
466 complementary way to adapt is to reconsider *why* forests are managed and not only *how*. Nowadays,
467 foresters supply wood to respond to societal timber demands and balance their forest budgets. While
468 our societies will very likely still require timber, the way in which climate change challenges financial
469 equilibriums can also be worked on with organizational and economic tools. For instance, the current
470 literature proposes the inclusion of adaptation planning in forest certification (Spittlehouse and
471 Stewart 2004), while projects flourish with the payment for ES (e.g., carbon storage (Gren and Aklilu
472 2016)) and the revaluation of timber by quality labels (e.g., <http://bois-de-chartreuse.fr/>). To some
473 extent, such initiatives can contribute to climate change adaptation by decreasing the economic
474 pressure put on timber production. By opening up many possibilities, these projects also broaden the
475 principle of “not putting all your eggs in one basket,” as they diversify not only the practices of timber
476 production, but also the plurality of other forest ES and downstream forestry organization.

477 To end with a practical proposal, we suggest that the collective design of complementary
478 adaptations could draw on serious games. Often described as environmental models coupled with
479 digitalized games (Reckien and Eisenack 2013), serious games are a promising means to develop
480 entertaining education and learning, but also prospective simulations (Reckien and Eisenack 2013; Wu
481 and Lee 2015; Garcia 2019). These represent riskless opportunities for foresters to try to design non-
482 technical tools prone to contribute to their adaptation to climate change along with technical
483 evolutions.

484

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486

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492

493 **Declarations of interest**

494 None.

495

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