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

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Highlights

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

Abstract

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

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

1. Introduction

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

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

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

In line with the need to adapt, an abundant body of literature now confirms how “climate-proof” paradigms of forest management have arisen such as adaptive management (Linder 2000; Noss 2001; Bolte et al. 2009) and the consideration of uncertainties by diversifying silvicultural practices and objectives (Keenan 2015; Augustynczik et al. 2019). However, in comparison, very little research has explored how foresters currently handle the impacts and uncertainties of climate change in the field (Kolström et al. 2011; Van Gameren 2014; Nelson et al. 2016).This is of the highest importance, because concrete changes drive forest ecological trajectories, and feedback from the field can help to improve public policies related to forest management (Brockerhoff et al. 2017; Williamson et al. 2019).

Therefore, the rationale of this study is to describe the field adaptations and the drivers that could have been implemented in the temperate forest sector. It draws on interviews with French forest managers (owners, private forest advisors, or public practitioners). Three reasons motivate the choice of this country as a study case. First, the country has a vast forested area (169,000 km^2, the third largest volume in Europe; IFN 2018). Second, its timber industry is economically important for employment, which influences public policies for its adaptation to climate change (MAAF 2017). Third, France is expected to experience the impacts of climate change in all its forest ecosystems (ONERC 2015).

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

2. Materials and methods

2.1. Study cases

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

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

The second study area, the "Landes de Gascogne" (hereafter "Landes"), is a human-made forest in southwestern France. After two centuries of intensive management, it expanded by draining the former marshlands (Deuffic et al. 2010). Nowadays, the monoculture of maritime pines (*Pinus* *pinaster*) requires the plowing of soil, the planting of selected seedlings, and the clearcutting of trees between their 30th and 40th year. Private ownership represents 95% of the total surface, making the Landes forest one of the largest privately owned forests in Europe (Deuffic et al. 2010).

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

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

2.2. Data collection

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

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

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

2.3. Characterization of evolutions in forest management

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

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

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

3. Forestry evolutions not driven by climate change adaptations

3.1. Mainstreaming of forest management in the timber industry

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

Upstream activities include proper forestry operations such as the choice of forest regeneration and logging practices. Mechanization was by far the most cited evolution (9 interviews), with a more frequent use of harvesting machines and more powerful machines, as illustrated by interviewee L5: "There is a clear evolution. It is the acceleration of mechanization, of its intensity, and… It is the increase in the power of the machines." The prevailing place of mechanization is a common evolution in forestry, which is also found in other national contexts (Heinimann 2007; Marchi et al. 2018).

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

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

3.2. Climate change adaptation: Reaction first

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

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

Among the 14 foresters who associated these 27 adaptations to droughts and storms, 9 had already changed their forest management in order to account for such hazards, while another 2 had launched experiments on technical adaptations such as assisted migration. The 11 other adaptations to climate change mentioned by 6 different foresters related to a mixture of different sources of stress (parasites, phenological changes, etc.) or parasite attacks (n=3) (Fig. 1) and were partially operational in the field.

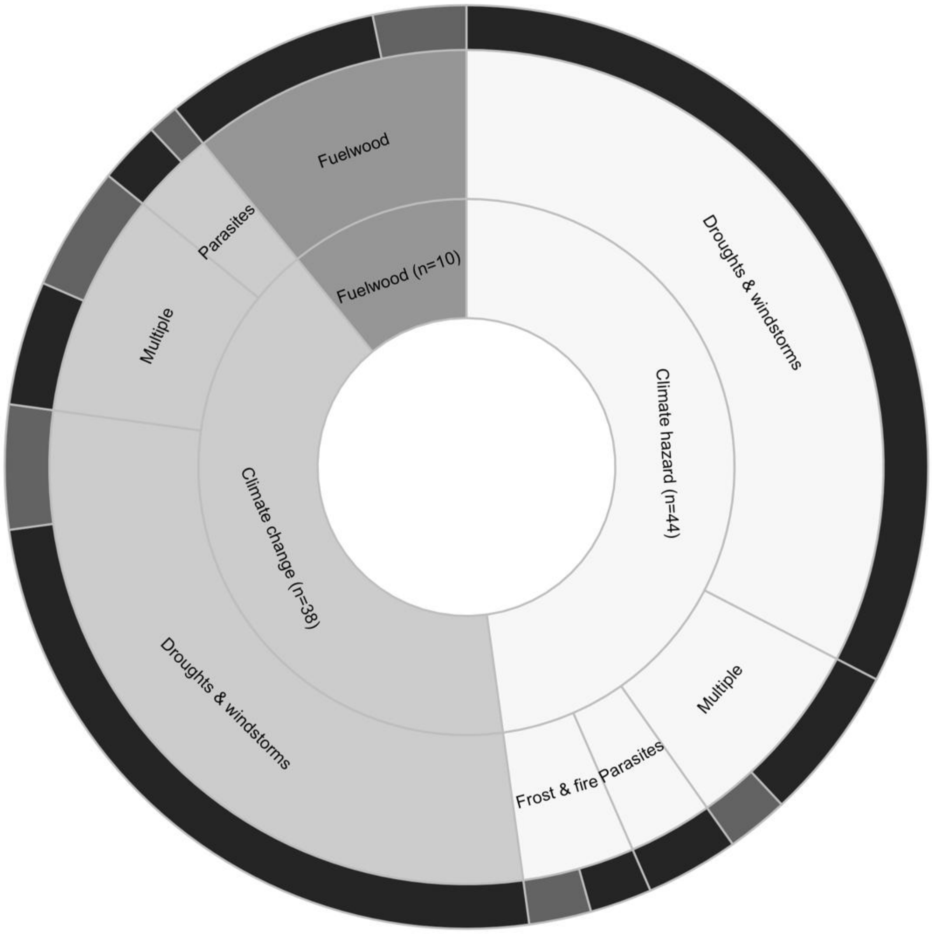

Figure 1. Climate-related drivers of forestry evolutions and their implementation. Interview samples labeled as "climate hazards" differ from those mentioning "climate change," as the evolution of forestry practices does not result from a change in the climate. The rising demand for fuelwood due to public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

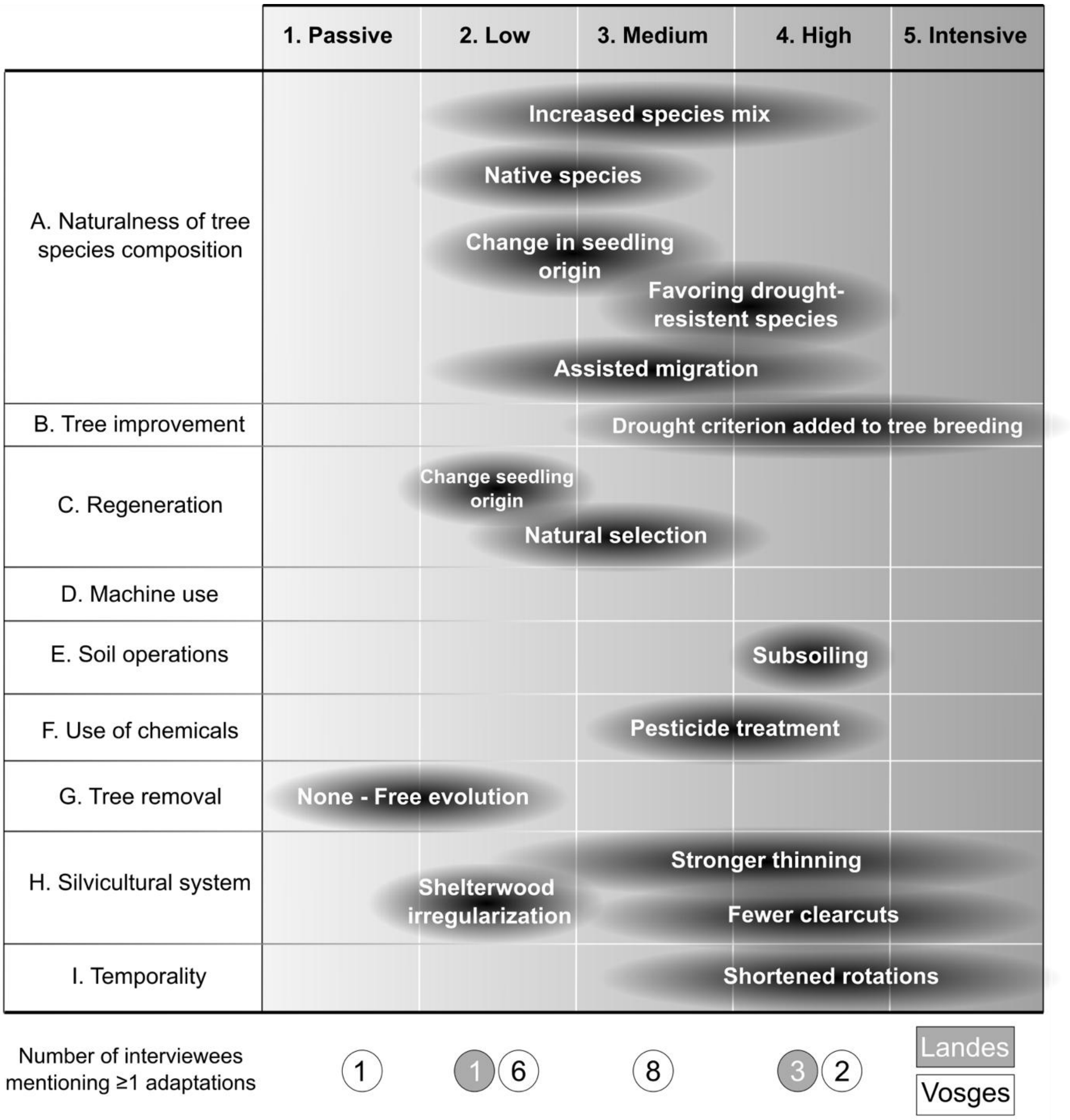

Figure 2. Climate change adaptations rely on technical operations at different decision stages of forest management.

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

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

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

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

4.1. Adaptation: Change of practices, continuity of objectives

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

This finding was expected, as productive ES contribute the most to forest-based revenues (Cinotti 2003), as stated by interviewee V13 regarding water epuration and carbon storage: "The owner only makes money from timber sales, being about 90% of revenues, with only 10% coming from hunting leases. Up to now, what's left is for free, a gift to society!" Adapting for timber production is of great interest, as it encourages the use of wood as a renewable and potentially sustainable source of material and energy (Baral 2004). However, losing sight of non-productive ES in climate change adaptation could have dramatic effects, as climate change also affects forest-based water supply (Ford et al. 2011) and local or regional climate cooling (Ellison et al. 2017). This could have adverse effects on forest leisure services (Gray et al. 2009) or biodiversity functioning in forest ES (Brockerhoff et al. 2017).

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

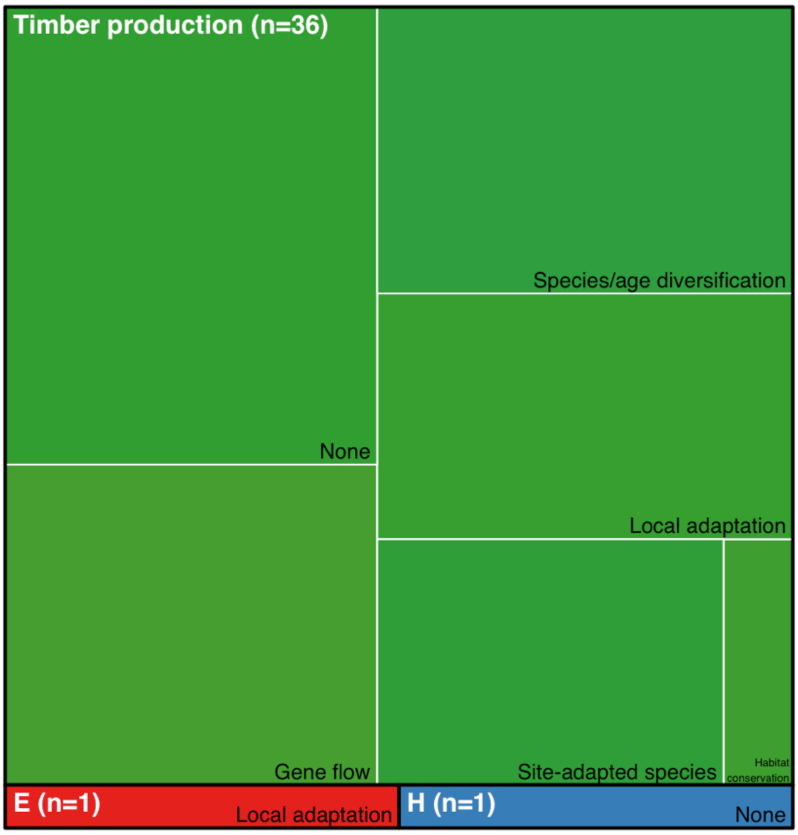

Figure 3. Forestry adaptations to climate change focus on productive ecosystem goods and services. In a treemap, the size of the cells is proportional to their importance. In white, the objectives of climate change adaptations, as expressed by the interviewees: E = ecological conservation (conservation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

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

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

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

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

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

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

In this highly uncertain context of climate change, foresters do their best to prepare to future climate hazards, but they especially favor these adaptations addressing their current concerns. This fuzziness led to the use of technical arguments in order to legitimate their own preference for a particular kind of forest management, as phrased by interviewee V1 with regard to shortened rotations: "Under the pretext of climate change, the timber industry could sneak in." In the case of windstorms, for instance, the Vosges interviewees insisted on irregular shelterwood and species mixtures, thus rejecting even-aged silviculture: "The cathedral forest, it's over! It is way too vulnerable to windstorms" (V5). However, in the Landes, many interviewees were convinced of the opposite: "There's not many solutions. We need an even-aged treatment, where we control the harvest, so that we have thick stems allowing for the individual stability" (L9). Other examples of technical discussions exist such as the use of exogenous species to cope with parasite attacks and changes in the thinning intensity. Arguments in favor of more biodiverse forests were also used in discourses on adaptation to climate change, especially by the interviewees most attached to ecological conservation.

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

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

5.1. An instrumental vision of ecological processes in adaptive changes

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

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

However, it is not because climate change adaptations prioritize the intrinsic value of biodiversity and natural habitats that they necessarily involve a higher intensity of forest management (Fig. 2). Even if it was not prevalent in the interviews, the growing recognition of ecosystem-based adaptation to climate change resonates with the development of close-to-nature forestry (Gamborg and Larsen 2003; Naumann et al. 2011). Two interviewees, both prominent members of the French ProSilva branch (ProSilva 2017), stressed the long-term ecological and economic resilience to climate change provided by irregular shelterwood, selective thinning, and species mixture: “A diverse system is more stable, as it lasts better than a ‘house of cards’ system” (V13). It must also be said that intensive management should not be banned from adaptations aimed at ecological conservation: it can be a prerequisite for operations focused on ecological restorations or rehabilitation (e.g., Fouqueray et al. 2018), all the more in a rapidly changing context (Aitken et al. 2008).

5.2. Impacts of climate change adaptations on ecological processes

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

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

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

With respect to ecological processes, the most noticeable output of the interviewees was the lack of focus on the landscape scale. Almost all adaptations were applied to the tree or stand level, whereas ecological and evolutive processes occur at much wider spatial scales. This discrepancy was obvious in the Landes, with all but two interviewees considering the role of biodiversity to be an external variable of forestry and adaptation. In this forest heavily constrained by soil conditions and economic pressure, the changes in practices relating to biodiversity were confined to the borders between forest stands: “We know that broadleaved trees resist better [to windstorms], that they have advantages in terms of humus, parasite resistance, etc. So yes, we’re pushing ourselves to create wooded corridors along roads and ditches” (L11).

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

6. Conclusion

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

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

Nevertheless, our findings raise two concerns in terms of how foresters currently apply adaptation decisions. First, we underlined how foresters displayed a preference for slowly reversible changes and how they discarded landscape ecological processes in their management changes. This can lead to adaptations suitable for a specific time and place at the expense of adaptations for the future or at another spatial scale (Carpenter et al. 2001). In a context of high uncertainties, no-regrets and reversible solutions are a way to avoid potential collateral damages to the current adaptations, either later or elsewhere. Ecosystem-based adaptations and nature-based solutions have been depicted as emerging adaptation mechanisms that account for these limitations of the current adaptation (Balian et al. 2014; Eggermont et al. 2015). Second, the lack of regional concertation around adaptations (especially in private forests) hinders the elaboration of complementary regional approaches that could integrate ecological issues. If set up, concertation considering social logics could support learning exchanges by distributing experimental stands at the regional scale (Andersson and Keskitalo 2018). It could also be a way to tackle other forest hazards associated with climate change and amplify them such as the overload of wild grazers.

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

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

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Declarations of interest

None.

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