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The determinants of adapting forest management practices to climate change: Lessons from a survey of French private forest owners

Thomas J.¹, Brunette M.², Leblois A.³

October 22, 2021

Abstract

Climate change seriously impacts forest ecosystems. In order to maintain a healthy and sustainable forest cover, adaptation strategies should be implemented. This article proposes to deepen our understanding of the decision-making process of private forest owners in terms of adaptation decisions towards climate change. In particular, we question whether or not French private forest owners have already implemented adaptation strategies and if yes, we identify the determinants of this decision. ~~the aim is to identify determinants of adaptation decisions.~~ We focus on the identification of the determinants of the probability to adapt and on the determinants of adopting each strategy separately (early harvest, thinning, irregular silviculture). A survey of more than 900 French private forest owners was conducted for the purpose of collecting both (1) objective variables: characteristics of the owners and the property; and (2) subjective variables: perception of climate change and impacts. The results reveal that both types of variables are complementary to explain the adaptation decision. In addition, we show that the determinants are different from one adaptation strategy to another, meaning that the adaptation decision should not be thought of in general but, instead, strategy-by-strategy.

Keywords: adaptation, forest, survey, French private forest owners.

JEL codes: Q23 (Forestry); Q54 (Climate • Natural Disasters and Their Management • Global Warming)

DECLARATIONS

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41 1. Introduction

42 Climate change ~~will~~ has serious impacts on forest ecosystems, altering the provision of goods and services
43 worldwide. The increase in temperature and reduction in the precipitation regime affects growth and productivity
44 (Ma et al. 2019) and will result in decline and mortality (Cohen et al. 2016; Send et al. 2020; ~~Borgh et al. 2003;~~
45 ~~Jump et al. 2006~~). In the same way, the increase in frequency and intensity of natural events (~~Flannigan et al.~~
46 ~~2000; Fuhrer et al. 2006~~ Seidl et al. 2020; Zscheischler et al. 2018) suggests large losses in future forest value
47 (Hanewinkel et al. 2013) in the coming years. Forest disturbance damage in Europe has increased throughout the
48 20th century (Schelhaas et al. 2003) and has continued to rise in the first decade of the 21st century (Seidl et al.
49 2014), mainly due to climate change (Seidl et al. 2011). Damage from wind, bark beetles and forest fires is likely
50 to increase even more in coming decades, and the rate of increase is estimated at $+0.91 \times 10^6$ m³ of timber per
51 year until 2030 (Seidl et al. 2014). In France, where the forest cover encompasses 31% of the territory with a
52 total of 16.9 million hectares (IGN 2020), and where the forest sector directly employs 395,000 people, for an
53 added value of €26.1 billion, representing 1.08% of the French GDP (VEM 2019), these impacts may be
54 detrimental.

55 The speed of environmental changes is such that implementation of adaptation strategies by foresters is required
56 to maintain a forest cover (Spittlehouse and Stewart 2003). In this context, a wide range of adaptation strategies
57 are recommended: reduction of harvest rotation length, reduction of density at the time of plantation, adoption of
58 species better adapted to the future climate, species mix, uneven-aged stands, etc. (Spittlehouse and Stewart
59 2003; Ogden and Innes 2009). These adaptation strategies are linked to mitigation strategies, especially since
60 they favour tree growth and carbon storage (Verkerk et al. 2020). Indeed, a “successful mitigation strategy must
61 consider adaptation measures to ensure the resilience of forest ecosystems (Schoene and Bernier 2012)”. Millar
62 et al. (2007) also insist on the fact that resource managers need to integrate both adaptation and mitigation
63 strategies into forest management plans. Consequently, in this paper, we focus on adaptation strategies as a
64 prerequisite to mitigation. However, to implement adaptation, foresters must be aware that climate change is
65 actually occurring, they must perceive the threat that climate change represents for their forests, and they must be
66 able to make often irreversible decisions.

67 In the framework of international negotiations about climate change, forests have a main role to play ~~in terms of~~
68 ~~mitigation~~. Public authorities are thus under pressure to implement policies and projects that facilitate adaptation
69 (Van Aalst 2006; Hochrainer-Stigler et al. 2014). However, little information exists about the ~~French~~ private
70 forest owner’s adaptation decisions, which are the relevant decision unit in France because 75% of the forest
71 area is privately owned by 3.3 million private forest owners. Exploring their choices in terms of adaptation with
72 the aim to identify major determinants ~~the determinants of their adaptation choices~~ is thus critical for policy
73 makers. Indeed, better knowledge of how these choices are made and why is essential to understand the triggers
74 of adaptation strategies. Moreover, policy makers rely on such information to design public policies that aim at
75 creating incentives for owners to adapt to climate change. A better understanding of the ~~drivers~~ determinants of
76 adaptation strategies will make it possible to increase the efficiency of public policies for both mitigation and
77 adaptation.

78 In this context, many research questions have emerged: Are ~~French~~ private forest owners aware of climate
79 change? How do they perceive the impact of climate change? Have they already modified their management
80 practices in view of climate change? If yes, which adaptation strategies have they adopted and why? If not, why
81 choose to not adapt?, etc. More generally, we address the question of the determinants of the adaptation
82 decisions of French private forest owners in order to identify levers to encourage them to adapt. For that purpose,
83 we ran a phone survey with 960 respondents, selected by plot size and region using a stratified sampling method
84 among eight regions and four forest area classes. Descriptive statistics made it possible to characterise French
85 private forest owners, their property, the way they perceive climate change and their adaptive capacity. We used
86 probit regressions to identify the determinants of the adaptation choice. In addition, the high number of
87 respondents allowed us to estimate the role of each determinant for every adaptation strategy considered, which
88 allows us to identify strategy-dependent determinants.

89 2. Literature review

90 ~~Private forest owners’ adaptation decisions have been widely addressed in the literature.~~ An interesting literature
91 review by Keenan (2015) inventories 1172 research articles on climate change impacts and management options
92 for adaptation to climate change. He shows that only 12% of the papers considered adaptation options. He
93 concludes that research to support adaptation to climate change is still heavily focused on assessing impacts and
94 vulnerability. He underlines that “Knowledge gaps lie more in understanding the social and community attitudes
95 and values that drive forest management and the decision making processes of forest managers“. In this sense,
96 our article directly contributes to filling in this gap.

97 Another literature review proposed by Brunette et al. (2018) is restricted to 89 articles, simultaneously dealing
98 with climate, adaptation, risk and economy. The articles were categorised into three distinct groups that affect
99 adaptive decisions: (i) profit and production; (ii) microeconomic risk-handling; and (iii) decision and behaviour.
100 The third group is of particular interest since it includes social and behavioural variables that affect management
101 decisions collected through questionnaires. In that third group, we can find, for example, articles dealing with
102 forest owner's perceptions (Blennow and Sallnäs 2002 ; Eriksson 2014) and attitudes towards risk (Sauter et al.
103 2016 ; Brunette et al. 2017).

104
105 Our article is directly linked to this literature that focuses on the determinants of the forest owner's decisions.
106 However, since we only focus on adaptation decisions, in the following literature review, we only selected
107 articles that deal with the determinants of adaptation strategies among foresters, based on a survey. These articles
108 make it possible to identify relevant determinants of adaptation and to justify our approach.

109 ~~In particular, numerous articles focus on use surveys of private forest owners to analyse concerning their~~
110 ~~adaptation decisions, and making it possible to identify relevant determinants of adaptation.~~

111 Van Gameren and Zaccai (2015) carried out a qualitative survey with semi-structured interviews of 32
112 private forest owners in Wallonia, Belgium. They investigated climate change adaptation practices that had
113 already been implemented or considered as well as the adaptive capacity of the owners. They showed that socio-
114 cognitive variables related to personal representations about forest management, climate change risks and
115 adaptation must not be neglected since they interact with more objective variables like the features of the forest
116 property, forest owners' knowledge resources, and institutional incentives.

117 Through an online survey of 220 private forest owners (and 171 public managers) from Belgium,
118 Sousa-Silva et al. (2016) studied how they perceive the role of their forest management in the context of climate
119 change and the impediments that limit their ability to prepare and respond to these changes. They showed that
120 most of the respondents are aware of climate change. They also indicate that private owners are, on average, less
121 likely to have adapted their management practices than public managers. The main brake to this implementation
122 is the lack of information.

123 Fischer (2019) implemented a qualitative analysis of 85 private forest owners involved in focus groups
124 in the upper Midwest of the United States. The objective was to evaluate forest owner's responses to local forest
125 stressors linked to climate change. She found that forest owners' responses were planned as well as autonomous,
126 more proactive than reactive, incremental rather than transformational, and aimed at being resilient to change
127 and transitioning to new conditions rather than resisting change alone. She also showed that many of the
128 landowners' responses can be considered as forms of adaptation rather than coping mechanisms because they
129 were aimed at moderating and avoiding harm on long-term horizons in anticipation of change.

130 Vulturius et al. (2018) looked at the adaptation process of 836 Swedish private forest owners. In
131 particular, they assessed and compared the role of cognitive, experiential and structural factors on individuals'
132 climate change adaptations. They showed that cognitive factors (i.e., personal level of trust in climate science,
133 belief in the salience of climate change and risk assessment) are the only statistically significant factors
134 explaining the forest owner's intention to adapt to climate change. The other factors (structural or socio-
135 demographic) do not have a significant impact, like, for example, age, gender, education, forest size and income
136 level.

137 Using data from online surveys of 1131 forest owners and managers from seven European countries
138 (203 respondents from France), Sousa-Silva et al. (2018) assessed how they perceive their role in adapting forest
139 management to climate change. The surveys deal, among other things, with the impacts of climate change and
140 the way foresters consider climate change in their management decisions. Their main conclusion is that results
141 are country-dependent with variability in terms of perceptions and actions. They identified some relevant actions
142 such as changes in species mix and assistance in tree regeneration. They also found that forest owners and
143 managers from France (along with the Slovakian ones) have the largest share of individuals who have
144 undertaken adaptation strategies.

145 More recently, Eriksson and Fries (2020) collected 1251 Swedish private forest owners' answers to a
146 postal questionnaire aimed at examining the current knowledge (objective knowledge), confidence (subjective
147 knowledge) and value basis of forest management behaviours, including different management strategies
148 (management for production, biodiversity, recreation, climate adaptation, climate mitigation) and management
149 inactivity. The results revealed that different knowledge dimensions and value priorities both contributed to
150 forest management behaviours. In addition, the importance of the role of the forest owner's identity (self-identity
151 and social identity) on management behaviours was confirmed. They were able to show that variables related to
152 forest and forest owners have an impact on the adaptation decision (significant and positive effect of forest size,
153 significant and negative impact of gender).

154 Finally, Brunette et al. (2020) carried out an online survey of 88 forest managers from Germany and
155 France. First, they measured their attitudes towards risk and uncertainty and collected socio-demographic
156 information. Second, they observed the effect of these variables on the probability to adapt and on the intensity

157 of adaptation. They showed that the probability to adapt is negatively impacted by risk aversion, being French
158 (as compared with being German) and the variable age, whereas the level of income has a significant and
159 positive impact. They also observed that only two variables explain the intensity of the adaptation. Being French
160 and being risk-averse have a significant and negative impact on the number of adaptation strategies selected by
161 the individual.

162 On the basis of this ~~short~~ literature review, several comments can be made, making it possible to justify our
163 approach.

164 ~~First, it appears that several determinants of private forest owners' adaptation decisions are identified~~
165 ~~and classified. A first category of variables, referred to as "Objective variables" by Van Gameren and Zaccai~~
166 ~~(2015), "characteristics of respondents" by Sousa-Silva et al. (2016, 2018) and "socio-demographic" variables~~
167 ~~by Vulturius et al. (2018) and Brunette et al. (2020), deals with the characteristics of the forest owner (gender,~~
168 ~~age, etc.) and the forest property (surface area, management document, etc.). A second category, referred to as~~
169 ~~"socio-cognitive variables" by Van Gameren and Zaccai (2015), "beliefs" by Sousa Silva et al. (2016, 2018)~~
170 ~~and "cognitive factors" by Vulturius et al. (2018), consists of variables related to climate change such as~~
171 ~~perception of climate change, expected impact of climate change, etc. We retained these two categories of~~
172 ~~variables and used them to build our questionnaire.~~

173 ~~Second~~First, the literature converges towards the idea that some adaptation strategies seem to be
174 prioritised or will be prioritised in the future by foresters, like the increase in the species mix and assistance in
175 tree regeneration (Sousa-Silva et al. 2018). However, to our knowledge, no article has yet to explain what the
176 determinants are that encourage foresters to adopt one of these strategies rather than another.

177 ~~Third~~Second, only the ~~some articles focus on the adaptation practices in one country at a time, like~~
178 ~~Belgium, the USA and Sweden, and one paper proposes a~~ multi-country survey of Sousa-Silva et al. (2018) and
179 Brunette et al. (2020) considered ~~with a sample of 203~~ French foresters. However, these samples are not focused
180 on private forest owners and are rather "small". This means that understanding the adaptation decisions of
181 French private forest owners is still a challenge that we attempt to tackle in this article.

182 In this context, we propose to analyse the French private forest owners' ~~revealed preferences~~ choices in terms of
183 adaptation strategies when faced with climate change. We explore their adaptation choice (yes or no) and analyse
184 the determinants of their choices (objective and subjective variables).

185 3. Conceptual framework

186 Based on the literature review, it appears that several determinants of private forest owners' adaptation decisions
187 are identified and classified.

188 A first category of variables, referred to as "Objective variables" by Van Gameren and Zaccai (2015),
189 "characteristics of respondents" by Sousa-Silva et al. (2016, 2018) and "socio-demographic" variables by
190 Vulturius et al. (2018) and Brunette et al. (2020), deals with the characteristics of the forest owner (gender, age,
191 education, profession) and the forest property (surface area, management document, location, income from
192 forestry).

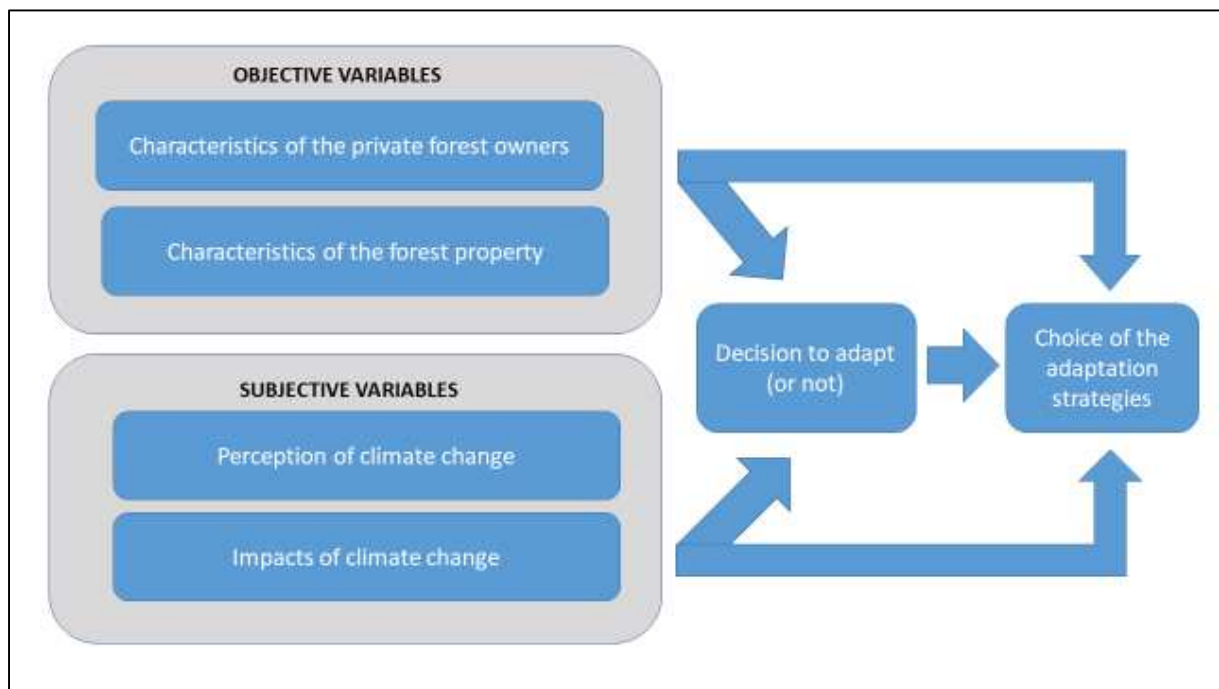
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195 climate change such as perception of climate change, expected impact of climate change, etc.

196 We retained these two categories of variables and we propose the conceptual framework in Fig. 1 to analyse their
197 impact on the adaptation decision of French private forest owners and on the choice of the adaptation strategy to
198 be implemented. Indeed, in a first step, we will identify the determinants of the probability to adapt, and, in a
199 second step, among those who already adapt their management and choose to implement strategies, we propose
200 to identify determinants of these strategies.

201 The choice of the questions in each category, objective and subjective variables, is based on the existing
202 literature and is the result of a long process of discussions and negotiations with the stakeholders. Indeed, this
203 questionnaire is part of a project involving different actors from the French forestry sector. The questionnaire
204 had been extensively discussed and modified to reach a consensus. We present here the results for this
205 consensual questionnaire. We do not try to be exhaustive in the variables considered. Our objective during the
206 building of the questionnaire was to identify potential relevant variables that can explain the private forest

207 owner's adaptation choices in France, and to formulate the associated questions to capture these relevant
208 variables.

209 For example, Brunette et al. (2020) found the variables that capture age and income to be significant and
210 Eriksson and Fries (2020) found gender and forest size to be significant as well. Consequently, we consider that
211 they can influence both the decision to adapt and the choice of adaptation strategy. Other more specific variables
212 are considered. For example, income from hunting was identified during our discussions with stakeholders as an
213 important variable to consider because this practice is very developed in France. The idea is that people who pay
214 to hunt also pay for a hunting environment (with the landscape and amenities aspects) and, consequently,
215 changing practices to adapt may affect this environment and represent a potential brake to adaptation.



216

217 Figure 1. Conceptual framework of French private forest owners' adaptation decisions and choices.

218 More precisely, the objective variables are the characteristics of the owners (age, gender, profession, education),
219 and the characteristics of the forest property (area, location, management document, source of revenue and
220 management objective). These variables were also part of the studies referred to in the literature review and are
221 known to influence forest adaptation. The subjective variables are the perception of climate change, the origin of
222 climate change, the impact of climate change, the timing of impact, the feeling about these impacts and the
223 manifestations in the field. Beliefs, convictions and perceptions in the salience of climate change have been
224 found to be the strongest determinants of adaptation decisions (Blennow et al. 2012).

225 4. Materials and Methods

226 4.1 Definition of adaptation strategies

227 As mentioned above, Fischer (2019) found that landowner responses were mainly planned, proactive and
228 incremental. Proactive adaptation entails reorienting practices in anticipation of new conditions in order to
229 reduce future damage, risk and vulnerability. Incremental adaptation refers to making small changes in current
230 contexts to avoid disruptions and continue pursuing the same objectives. Planned adaptation involves intentional
231 efforts to obtain information about present and future changes, taking the suitability of current and planned
232 practices and policies into account.

233 In terms of forestry, many adaptation strategies have been proposed. In particular, we retained three of them
234 from the 30 proposed by Ogden and Innes (2009) : “reduce the rotation age” (*Early harvest*), “modify thinning
235 practices” (*Thinning*) and “apply silvicultural techniques that maintain a diversity of age stands and mix of
236 species” (*Irregular*). All things considered, these three strategies seem to be relevant for our article, their
237 effectiveness is not subject to discussion in terms of adaptation to climate change in the literature, and they are in

238 line with Fischer (2019) in the sense that they correspond to planned, proactive and incremental adaptation
239 strategies. Moreover, they are relevant for French forestry, as discussed below.

240 Growing stock, old and large trees are expected to increase the vulnerability of forests (Seidl et al. 2011). In
241 keeping with Lafond et al. (2014), we can say that limiting forest stocking through more intensive management
242 (i.e., *Early harvest*) is assumed to be an adaptation strategy to lower forest vulnerability (Puetzman 2011) by
243 limiting competition for water (Sohn et al. 2012) and exposure time to risk (Loisel 2011), especially insect
244 attacks and diseases (Gottschalk 1995). In addition, *Early harvest* also makes it possible to accelerate the
245 establishment of better-adapted forest types and tree species (Ogden and Innes, 2009; Lindner et al. 2000; Parker
246 et al. 2000). From an economic perspective, reducing the rotation length has already proved to be efficient to
247 lessen the risk of forest decline (Bréda and Brunette 2019).

248 Modifying *Thinning* in timing or intensity makes it possible to increase growth and turnover of carbon (Ogden
249 and Innes 2009). In addition, thinning improves the recovery of radial growth following drought and, to a lesser
250 extent, growth resistance during a drought event (Sohn et al. 2016). Partial cutting or thinning also leads to
251 increased stand vigour and lowers susceptibility to biotic attacks (Wargo and Harrington 1991; Gottschalk 1995).
252 Finally, thinning makes it possible to increase solar radiation, water and nutrient availability to the remaining
253 trees (Smith et al. 1997; Papadopol 2000).

254 The *Irregular* strategy makes it possible to diversify the stand in terms of species and age, to have a continuous
255 cover and to then reduce the associated risks (Ogden and Innes 2009). In addition, and consistent with Lafond et
256 al. (2014), uneven-aged structures allow the permanence of high regeneration cover in the stand (O'Hara 2006;
257 Cordonnier et al. 2008) and create complementarities in species sensitivity or response to disturbance (DeClerck
258 et al. 2006; Jactel and Brockerhoff 2007).

259 **4.2 Questionnaire design**

260 The survey ~~was conducted in 2018 on 944 private forest owners from metropolitan France by the Research~~
261 ~~Centre for the Study and Observation of Living Conditions (CREDOC). It consisted of a phone survey with 37~~
262 ~~questions that took an average of 10 minutes to answer.~~

263 The questionnaire was composed of different parts. These parts correspond to the categories of variables already
264 identified in the literature. Indeed, the first part of the questionnaire is dedicated to “Objective variables” linked
265 to the characteristics of the forest owner and forest and the second part deals with “Subjective variables” related
266 to climate change (perception and cause, observation and impact). The last part consists of questions for the
267 forest owners about potential changes of practices in order to adapt to climate change. Consequently, the answers
268 provided by the private forest owners in the first two parts are then used to explain the adaptation choices
269 expressed in the third part. The questions asked in each part of the questionnaire are presented in Appendix A.

270 **4.3 Description of the sample**

271 The survey was conducted in 2018 on private forest owners from metropolitan France by the Research Centre for
272 the Study and Observation of Living Conditions (CREDOC). The CREDOC had the phone numbers of more
273 than 6000 French private forest owners. Among them, 3827 owners could not be reached, 760 were contacted
274 but turned out to be off-target (too small surface area, errors in the plot held, etc.), 789 simply refused to answer
275 and 944 fully completed the questionnaire.

276 The sample was drawn up from a double stratification, by region and area class. Surveyed owners were selected,
277 first, according to the location of their forest (region) and, second, according to the forest surface area they
278 owned. All regions and forest area classes are represented in our final sample.

279 The stratification by large region was carried out in order to differentiate the various types of climates found in
280 France (oceanic, continental, Mediterranean and mountain) and the type of associated stands with their own
281 constraints and number of private forest owners. Results were presented per region to ease their incorporation
282 into local public policies.

283 We randomly selected the same numbers of potential respondents for each region. We thus had eight regions (vs.
284 13 in the official sub-national divisions). Because some regions have similar climatic and settlement patterns, we
285 decided to group them together and select eight large regions represented by roughly equal samples in each
286 (compared to 13 in the official subnational divisions): (1) Auvergne-Rhône Alpes (119 respondents), (2) Corse-
287 Provence-Alpes-Côte d'Azur-Occitanie (114), (3) Bourgogne-Franche Comté (119), (4) Grand-Est (119), (5)

288 Centre-Val de Loire-Ile de France (112), (6) Nouvelle Aquitaine (117), (7) Bretagne-Pays de Loire (123), (8)
 289 Hauts de France-Normandie (121).

290 The stratification by area class is explained by the presence of management documents specific to the area
 291 category, and required by law as of 25 ha of forest owned, which explains why the largest properties must have a
 292 management document validated by a forestry consultant. Another point, consistent with other surveys
 293 conducted in France by the National Centre of Private Property (“Centre National de la Propriété Forestière”)
 294 and its partners revealed differences in owners’ behaviours according to the surface area they own, particularly
 295 in terms of their attachment to their forests, but also, for example, in terms of their expectations and behaviour
 296 with regard to wood cutting.

297 The 2016-2026 National Forest and Timber Program initiated by the Minister of Agriculture and Food has
 298 announced that the priority of the action of the National Centre of Forest Property will focus on owners with at
 299 least 4 ha, or about 76% of the private forest area, in order to assist them in the management of their forest. In
 300 view of the limited public resources (human and financial), the government has agreed to prioritise action for
 301 this population, targeting properties with the most favourable criteria in terms of economic development. The
 302 choice was therefore to follow this directive and focus on owners with 4 ha or more.

303 We considered four forest area classes: from 4 to 10 ha, from 10 to 25 ha, from 25 to 100 ha, and more than 100
 304 ha. The distribution was as follows: 314 owners in [4-10 ha], 161 in [10-25 ha], 399 in [25-100 ha] and 70 in
 305 >100 ha]. This makes it possible to reach national (or regional) level representativeness using weights.

306 4.3.1 Objective and subjective variables: Parts 1 and 2 of the questionnaire

307 Table 1 presents the descriptive statistics related to the first part (objective variables) and the second part
 308 (subjective variables) of the questionnaire.

309 **Objective variables.** Our sample is mainly composed of middle-aged men (45 to 65 years old). They show very
 310 heterogeneous education levels, with well-represented extremes: a large proportion of the sample has an
 311 education level lower than A level and the second largest share reached a master’s degree. The two most highly
 312 represented socio-professional categories (*SPC*) are farmers and executives.

313 Regarding the characteristics of the forest, we can say that the average forest area owned in our sample is about
 314 40 hectares, with a large variability: minimal area of 4 hectares and a maximal area of 2300 hectares. Most of the
 315 forest owners have forests of between 4 and 100 hectares; very few (less than 1%) own more than 100 ha.
 316 Private forest owners mainly own their forests for leisure-related reasons (*Obj_Leisure*) and biodiversity
 317 conservation (*Obj_Biodiversity*), although the answer to such a question could be relatively sensitive. Among the
 318 seven possible main reasons for owning forests, owners selected 4.5 of them on average, confirming the multi-
 319 functional characteristics of French forests and the non-specialisation of French forestry.

320 **Table 1. Descriptive statistics for objective (left) and subjective variables (right).**

Objective variables	Freq.	N	Subjective variables	Freq.	N
FORESTER					
Gender (female = 1)	76	944	Perception: Yes	287	944
Age < 44 years	35	944	Somewhat yes	406	944
45-65 years	656	944	Somewhat not	97	944
> 65 years	268	944	Not at all	74	944
Education: No diploma	51	944	Don't know	80	944
< A level	386	923	Anthropic: Yes	323	693
A level	125	923	Somewhat yes	274	693
2 to 3 years after A level	180	923	Somewhat not	37	693
Master	196	923	Not at all	56	693
SPC: Never worked	13	944	Don't know	3	693
Farmer	312	944	Impact: Large impact	307	693
Craftsman/Artisan	130	944	Small impact	252	693
Superior (executive)	248	944	No impact	34	693
Intermediary	122	944	Don't know	100	693
Employee	67	944	Timing: Today (already observable)	305	559
Worker (factory)	67	944	In 10 years	96	559
FOREST			In 30 years	104	559
Area (Min = 4.012 ha; Max = 2300.48 ha)		944	Don't know	54	559
4-10 ha	314	944	Feeling: Very worried	38	364
10-25 ha	161	944	Not very worried	272	364
25-100 ha	399	944	Don't know	54	364
> 100 ha	70	944	Manifestation: More drought	531	944
			More winter rain	322	944

Objective: Obj_Emotion	5	944
Obj_Heritage	5	944
Obj_Fiscal/Tax	1	944
Obj_Hunting	8	944
Obj_Timber	46	944
Obj_Biodiversity	106	944
Obj_Leisure	788	944
Manag_document	460	922
Revenue_12months	409	913
Among which: Revenue_logging	211	398
Revenue_hunting	146	398
Revenue_other	52	398
Regions: Auvergne-Rhône-Alpes	122	944
Bourgogne-Franche-Comté	121	944
Bretagne-Pays de la Loire	123	944
Centre-Val de Loire-Ile de France	114	944
Corse-PACA-Occitanie	115	944
Grand Est	122	944
Hauts de France-Normandie	122	944
Nouvelle Aquitaine	120	944

More storm	573	944
Less frost	412	944

321

322 Approximately half of the people in the sample own at least one formal document for forest management and
323 public regulation (*Manag_document*). The three documents considered are: Simple Management Plan (“Plan
324 simple de gestion”), Management regulation (“Règlement type de gestion”), and Codes of good silvicultural
325 practices (“Codes des bonnes pratiques”). When owners own more than 25 hectares of forest, they have to
326 provide a Simple Management Plan. It is required by law and well enforced.

327 Finally, the forest provided revenue over the last 12 months for 409 private forest owners (*Revenue_12months*),
328 mainly from logging.

329 The number of respondents is almost identical in each of the eight regions considered, approximately 12% of the
330 sample in each region.

331 **Subjective variables.** Approximately 73% of the private forest owners are aware of climate change (*Perception*)
332 and most of them think that it is human-induced (*Anthropic*). Most of the respondents are persuaded that climate
333 change will have an impact (either small or large), and they think that the impacts are already observable today
334 (*Timing*). Generally, the respondents are not very concerned by climate change impacts on their own forest (*Not*
335 *very worried*). We also questioned them about how climate change reveals itself in their forests and most of them
336 mentioned the increase in frequency and intensity of drought as well as storm events.

337 4.3.2 Adaptation choices: Part 3 of the questionnaire

338 Table 2 presents the descriptive statistics in terms of adaptation choices, i.e., Part 3 of the questionnaire. We ask
339 forest owners to indicate if they have changed their practices to address climate change for more than 5 years, in
340 the past 5 years, if they plan to do so in the next 5 years, if they have no plan or if they do not know.

341 We focused on a 5-year period for several reasons. The standard rotation period in France for forest management
342 is 10 years. This means that the forest owners attend to their stands approximately every ten years (with some
343 exceptions) to carry out silvicultural operations (thinning, harvest, etc.). As a consequence, our questions to the
344 forest owners concern the past five years and the next five years, in order to cover this 10-year rotation period,
345 and to ensure that some management actions have taken place during the period. In addition, considering a
346 longer time frame would create quality issues due to the impossibility of recalling certain details with precision.
347 Indeed, people may forget older changes and, in the same vein, it may be difficult for them to represent
348 themselves in the distant future. This 5-year time frame is commonly considered in the literature. For example,
349 Vulturius et al. (2018) asked private forest owners to state their intention to take risk-mitigating actions in the
350 coming 5 years. A 5-year period is also used to analyse harvesting decisions of private forest owners in Conway
351 et al. (2003), Garcia et al. (2014) and Brunette et al. (2017), among others.

352 We created a variable *Change_practices* that encompassed all the forest owners who had adopted adaptation
353 strategies in the past, both in the past five years and before. We chose to not consider those “who plan to adapt in
354 the next 5 years” because future changes are what is really going to happen but may explain how the propensity
355 to declare future changes can be fostered by a better understanding of individual behaviours and preferences
356 (rather than the future projection of changes). We can see that 16.1% have already changed their practices
357 (*Change_practices*). Among those who already adapt (*Past*), they mainly changed the way they thin (*Thinning*)

358 and have moved towards irregular stands (*Irregular*) as adaptation strategies. The factor that triggered the
 359 changes is specialised information in the forestry sector (*Specialised info*). The motivation to adapt is generally
 360 the desire to reduce the damage due to climate change (*Damage reduction*). To better assist them in their
 361 changes in practices, forest owners indicated that they were interested in specialised training (*Training*) on
 362 climate change and its regulations.

363 The forest owners who do not plan to adapt evoked the following reasons (*No change*): they think they can still
 364 wait (*Can wait*), current regulations limit their means of action (*Admin rules*), lack of money (*Money*) and other
 365 priorities regarding forest management (*Other priorities*).
 366
 367

Table 2. Adaptation decisions towards climate change.

Variable	Freq.	N
Change_practices	107	663
Past (for more than 5 years)	51	703
Past (in the past 5 years)	56	703
Plan (in the next 5 years)	127	703
No plan	429	703
Don't know	40	703
Among which "Past"		
Thinning	67	104
Early harvest	49	105
Irregular	66	104
Trigger: Professional advice	27	191
Friendly advice	13	191
Specialised info	101	191
Renewal_doc	50	191
Motivation: Ecosystem	1	225
Resilience	4	225
Productivity	12	225
Damage reduction	36	225
Support: Financial/tax	13	196
Technical assistance	17	196
Scientific answers	47	196
Training	119	196
No change: Limited info	4	382
Contradicting info	10	382
Can wait	130	382
Other priorities	56	382
Admin rules	71	382
User pressure	46	382
Money	65	382

368
 369 When looking at effective (*Past*) management practices, heterogeneities by area owned and region are relatively
 370 limited.

371 **4.4 Econometric strategy**

372 In the first step, we ran a probit regression on the binary variable *Change_practices*, taking the value of 1 for
 373 forest owners who had already begun adaptation and 0 otherwise (no adaptation undertaken). This regression
 374 allowed us to identify the determinants of the private forest owner's decision to adapt.

375 In the second step, we ran a probit regression per adaptation strategy, among the three included in the survey.
 376 This regression aims to highlight potential strategy-dependent ~~drivers~~ determinants that can only explain some
 377 strategies and not the general decision of adaptation.

378 Since each owner has to make binary choices, we have the following typical cross-section regression:

$$379 \quad x_i^* = \alpha_i + Z_i\beta + \mu_i \quad \text{avec } i \in 1, N$$

$$380 \quad x_i = 1 (x_i^* > 0)$$

381 where x_i^* is the latent variable of the adoption of adaptation strategies of owner i , and x_i is the binary variable of
 382 adoption (adaptation strategies); α_i is a dummy indicating the spatial unity (department/region) and Z_i is the

383 vector of explanatory variables. The explanatory variables are the objective and subjective variables presented in
384 Table 1 and represent the potential determinants of the adaptation decision.

385 Let $\Phi(\cdot)$ be the cumulative distribution function of observations: $PR(x_i = 1 | Z_i, \alpha_i) = \Phi(\alpha_i + Z_i\beta)$

386 Three models were run for each regression: a regression with a clustering of the standard errors at the department
387 level¹ (Model 1), a regression with a clustering at the department level and regional fixed effects (Model 2), and
388 a regression considering a clustering at the inter-regional level and regional fixed effects (Model 3). Standard
389 errors are more robust when clusters are large, and coefficients more precise with a lower level of fixed effects,
390 which makes the third regression the most robust. Consequently, we present the results of Model (3) in the
391 manuscript and the results associated with the other two models in Appendix B.

392 For each regression, we controlled for individual, property and location characteristics. We tested standard
393 individual controls such as age, education level and socio-economic status (socio-professional categories) of the
394 owners, as well as administrative variables (documents provided related to forest management). In addition, we
395 looked at the relationship between the reasons stated for owning woods and the climate change-related beliefs of
396 owners and their propensity to adapt.

397 5. Results

398 5.1 Adaptation vs. non-adaptation: the determinants

400 Table 3 presents the results of the regression for Model (3). The variable regressed is binary: *Change_practices*.
401 These regressions allow us to compare the determinants of those owners who have already adopted adaptation
402 (*Past*) and the others (*Plan, No plan, Don't know*).

403 The results are almost the same regardless of the model (Table 3 below and Table B1 in the Appendix present
404 the three models). Since education level and owner's age were not found to be significant ~~drivers~~ determinants in
405 any specifications, they were dropped from the result tables. It should be noted that the absence of a significant
406 impact of these two variables is in line with the results of Vulturius et al. (2020).

407 Some characteristics of the private forest owner and the forest are significant. Being a woman has a significant
408 and negative effect on the adaptation decision. This result is in line with Eriksson and Fries (2020). All of the
409 SPC also have a significant and positive effect compared to the category *Never worked*. Regarding the forest, the
410 area has a significant and positive impact, as in Eriksson and Fries (2020). The fact of having received revenue
411 from hunting is negative and has a significant impact with respect to *Other objectives*. This means that if owners
412 perceived revenue from hunting then they are less encouraged to adopt adaptation strategies. Indeed, changing
413 practices, with what this can generate in forest work and change in environment, has a negative impact.
414 Moreover, a change of setting can be associated with a loss of game, which, for example, would be less present
415 if the tree species on the spot are modified by better-adapted species. Some objectives indicated by the forest
416 owners for their forests appeared to always be positive and highly significant: *Biodiversity, Heritage, Leisure*
417 and *Timber*. Being able to provide a management document (*Manag_document*) has a significant and positive
418 impact on the decision. The location of the forest somewhere other than in NOUVELLE-AQUITAINE generally
419 has a significant and negative impact on the adaptation decision. One exception is BOURGOGNE-FRANCHE-
420 COMTE where the impact, although negative, is not significant.

421 Concerning the subjective variables, we observed that replying "Yes" to the question "Do you think the climate
422 is changing?" (*Perception_Yes*) has a significant and positive impact on the adaptation decision. We can observe
423 that respondents who think that climate change will have an impact (*Impact*) have a greater chance of adapting
424 their management. Regarding the way climate change manifests itself among the respondents indicates negative
425 and significant impact for *Less_frost* and *More_winter_rain*. Finally, people who consider that climate change
426 has an anthropic origin (*Anthropic*) have a lower chance to adapt than the others.

427

428

429

¹ The department is the second sub-national administrative boundary in France, after the region.

430 **Table 3. The determinants of the change in practices, inter-regional clusters and regional fixed effects.**

	Model (3)
Area	0.00208* (0.00109)
Revenue_12 months	-0.0367 (0.415)
Gender	-1.020** (0.473)
Farmer	4.144*** (0.240)
Craftsman/Artisan	3.624*** (0.293)
Superior	4.203*** (0.253)
Intermediary	4.155*** (0.281)
Employee	3.840*** (0.362)
Worker	4.745*** (0.241)
Manag_document	0.453** (0.200)
Revenue_logging	-0.529 (0.361)
Revenue_hunting	-0.377* (0.180)
Obj_Biodiversity	3.917*** (0.384)
Obj_Heritage	4.107*** (0.863)
Obj_Leisure	4.216*** (0.441)
Obj_Timber	4.014*** (0.742)
Impact ²	0.334* (0.168)
More_drought	0.269 (0.201)
Less_frost	-0.17** (0.0816)
More_winter_rain	-0.150* (0.0849)
Perception_Yes	0.418*** (0.165)
Anthropic ³	-0.319*** (0.123)
AUVERGNE-RHONE-ALPES	-0.686*** (0.0487)
BOURGOGNE - FRANCHE-COMTE	-0.0404 (0.0351)
BRETAGNE - PAYS de la LOIRE	-0.484*** (0.0915)
CENTRE - VAL de LOIRE - ILE de F	-0.872*** (0.0832)
CORSE - PACA - OCCITANIE	-0.332*** (0.0516)
GRAND EST	-0.254*** (0.0820)
HAUTS de FRANCE - NORMANDIE	-0.167*** (0.0628)
Constant	-8.049*** (0.586)
Observations	629
Department-level clustering	No
Regional-level clustering	Yes
Adjusted R ²	0.2101

Standard errors in parentheses; *p < 0.1; **p < 0.05; ***p < 0.01

431
 432 Respondents who had not changed their practices and did not wish to do so in the next five years (N = 429) were
 433 asked about the reasons for this refusal. These reasons are presented in Table 4.

434 **Table 4. Reasons for “no adaptation”, N=429.**

Variable	Freq
Reasons for not adapting	
Not enough information	60
Contradictory information	57
Prefer to wait	138
Other priorities	45
Money	48
Administrative rules	40
User pressure	21
Incentives to change	
Climate change assessment	49
Need insurance	18
Sanitary assessment	48
Experimental plot (impact evaluation) tests	46
Money	61

435
 436 The answer "Prefer to wait" was the most frequently given. The notion of information is also very important - it
 437 is cited by many respondents as either absent or contradictory. This idea of “lack of information” to explain the
 438 absence of adaptation is in line with Sousa-Silva et al. (2016). For those respondents who do not plan to change
 439 their practices, would certain tools or accompaniment encourage them to do so? Approximately 50% of the

² Impact has been coded as follows: Impact = 1 for “Large impact” and “Small impact”; Impact = 0 for “No impact” and “Don’t know”.

³ Anthropic has been coded as follows: Anthropic = 1 for “Yes” and “Somewhat yes”; Anthropic = 0 for “Somewhat not”, “Not at all” and “Don’t know”.

440 owners who do not wish to change their practices in the next 5 years are not interested (and/or do not know) in
 441 the proposals we have made to them (climate change assessment, insurance, sanitary assessment, experimental
 442 plots or money to assist them in adaptation). This may mean that our proposals were not varied enough or that
 443 these owners do not identify with the policies promoted by the forest and wood industry.

444 **5.2 Drivers Determinants of the adaptation strategies**

445 We first present bilateral correlations between the three adaptation strategies in Table 5. We observe that the
 446 correlations between strategies are low, meaning they are generally exclusive.

447 **Table 5. Bilateral correlations between the adaptation strategies.**

	Thinning	Early harvest	Irregular
Thinning	1.0000		
Early harvest	0.0753	1.0000	
Irregular	0.1465	0.0759	1.0000

449 Table 6 presents the regressions per adaptation strategy for Model (3).

451 **Table 6. Drivers Determinants by strategy, inter-regional clusters and regional fixed effects.**

	Thinning	Early harvest	Irregular
Area	0.000650 (0.00107)	0.00213 (0.00167)	-0.000272 (0.00124)
Revenue_12 months	-1.380* (0.719)	0.0316 (0.590)	0.0327 (0.782)
Farmer	-0.459 (0.548)	0.709 (0.604)	-0.0152 (0.506)
Craftsman/Artisan	-0.666 (0.768)	1.322* (0.777)	0.0940 (0.797)
Superior	-0.250 (0.522)	0.588 (0.572)	-0.263 (0.498)
Intermediary	-0.101 (0.611)	1.359* (0.697)	-0.398 (0.706)
Employee	-2.003*** (0.647)	0.465 (0.690)	-0.219 (0.836)
Manag_document	0.238 (0.367)	1.117*** (0.410)	0.962*** (0.340)
Revenue_logging	-0.959 (0.650)	0.242 (0.547)	0.128 (0.739)
Revenue_hunting	-0.122 (0.308)	-0.0438 (0.362)	0.188 (0.321)
Obj_Biodiversity	1.201 (0.837)	1.537* (0.870)	0.106 (0.506)
Obj_Leisure	1.417* (0.753)	1.436* (0.775)	0 (.)
Impact	-0.291 (0.535)	-0.615 (0.633)	0.612 (0.413)
More drought	-0.455 (0.466)	-0.510 (0.412)	0.0478 (0.388)
Less frost	0.362 (0.307)	-0.492* (0.264)	0.346 (0.273)
More winter rain	0.102 (0.258)	-0.240 (0.312)	0.393 (0.259)
Perception Yes	-0.127 (0.255)	-0.130 (0.310)	-0.103 (0.362)
Anthropic	-0.769* (0.447)	0.481 (0.434)	-0.430 (0.441)
Constant	2.933 (2.021)	-2.381 (1.664)	-1.127 (1.751)
Observations	97	98	93
Adjusted R ²	0.1333	0.3029	0.1978

452 Standard errors in parentheses; * p < 0.1; **p < 0.05; ***p < 0.01

453 Many of the variables have a significant impact on the strategy *Early harvest*. Belonging to the SCP
 454 *Intermediary* or *Craftsman/Artisan* encourages the French private forest owners to harvest earlier. In the same

455 way, owning a forest mainly for biodiversity conservation (*Obj_Biodiversity*) and leisure-related reasons
456 (*Obj_Leisure*) has a significant and positive impact on *Early Harvest*. Having a forest management document
457 acts like a high incentive to adopt *Early harvest*. Finally, respondents who consider that the impact of climate
458 change will be real (either *Large* or *Small*) are discouraged to harvest earlier.

459 Only one variable has a significant impact on *Irregular*. Indeed, having a forest management document
460 encourages French private forest owners to implement the adaptation strategy *Irregular*. This is also true for
461 *Early harvest*, showing a potential effect of public policies requiring a management document.

462 Having collected revenue from the forest over the last 12 months significantly and negatively affects the
463 *Thinning* strategy. Being an *Employee* has a significant and negative effect on *Thinning*. Being sure that the
464 origin of climate change is anthropic has a significant and negative effect on *Thinning*.

465 To conclude, we observe that: (i) adoption of the three adaptation strategies is not sensitive to the same drivers;
466 and (ii) there are significant variables in both the objective and subjective categories. We will address these two
467 results in the discussion.
468

469 6. Discussion

470 We first discuss our two main conclusions that deal with the strategy-dependent ~~drivers~~ determinants and the
471 complementarity between the categories of variables and, second, we discuss some potential limitations of the
472 article and prospects for future research.
473

474 6.1 Strategy-dependent ~~drivers~~ determinants

475 The intuition that the determinants of the adaptation decision are strategy-dependent turns out to be true since
476 none of the variables has the same significant impact on the three adaptation strategies considered. This means
477 that talking about adaptation in general may make no sense and that the incentives and design of public policies
478 should probably be dependent on the strategy. This also suggests that specific populations may be targeted for
479 the purpose of encouraging adaptation practices. For example, individuals belonging to the SCP *Intermediary* or
480 *Craftsman/Artisan* categories, who own a forest mainly for biodiversity conservation (*Obj_Biodiversity*) and
481 leisure-related reasons (*Obj_Leisure*), seem to be more prone to adopt *Early harvest*. Encouragement/incentive
482 policies may attempt to target those categories, or consider that having a forest management document and
483 questioning the impacts of climate change may also increase the probability of adoption.

484 The variable related to the management document increases the forest owner's propensity to adopt both
485 *Irregular* and *Early harvest* strategies, whereas it does not interfere (very small and insignificant coefficient)
486 with the adoption of *Thinning*. Although we cannot discuss the channels behind those relationships as they are
487 beyond the scope of this paper, it seems that owners who were able to provide a document to certify their forest
488 management (half of the people in the sample were able to provide either a simple or more detailed forest
489 management plan or at least a list of good practices) are more inclined to adopt these adaptation strategies. The
490 forest management documents thus represent a relevant vector for potential public policy dedicated to the
491 implementation of an adaptation strategy.

492 We also identified a large number of significant ~~drivers~~ determinants for the adaptation strategies based on
493 harvest management (*Early harvest*). Advancing the final harvest has been a classical risk management strategy
494 in forestry for a long time now and it is easy to implement throughout the rotation process. Moreover, this
495 strategy offers flexibility compared to the *Irregular* strategy. This result is in line with Brunette et al. (2020) who
496 observed that forestry professionals are afraid of changing routines and that current forest management practices
497 are characterised by inertia. In order to reduce this inertia, the improvement and clarification of the information
498 available to owners concerning climate change and its impact on forest management is an issue, as highlighted
499 by Sousa-Silva et al. (2016). Moreover, knowing that the climate is changing is not sufficient to initiate an
500 adaptation process. Indeed, private forest owners have to be convinced that the impacts of climate change will be
501 real, either small or large, to make the decision to adapt. This result confirms anecdotal evidence based on
502 descriptive statistics that show that private forest owners are in need of specialised information in the forestry
503 sector as well as training on climate change and its regulations. This result is also in line with Yousefpour and
504 Hanewinkel (2015) who show that "*forest decision-makers must be aware of the nature and implications of
505 climate change in order to develop management strategies that may help to reduce adverse effects and sustain
506 productive forests*".

507 Finally, when looking at the propensity of specific owners to adapt to climate change per region, we observed a
508 higher propensity in NOUVELLE-AQUITAINE (where pines, in majority, are grown intensively for paper pulp

509 production and related products) and in BOURGOGNE-FRANCHE-COMTE. Alternatively, CENTRE-VAL-
510 DE-LOIRE-Ile de FRANCE (the region encompassing Paris, the capitol) and AUVERGNE-RHONE-ALPES
511 (the region with the second biggest city in France: Lyon) seem to be the two regions with the lowest propensity
512 to adapt. This regional heterogeneity shows that our results should be interpreted with caution (also, because we
513 do not have owner fixed effects that would make it possible to more robustly control for individual and
514 especially unobservable specific characteristics). This is also in line with Spathef et al. (2014) who said that it is
515 “of utmost importance to implement regionally-based adaptation measures that are accepted by the stakeholders
516 involved”.

517 **6.2 Complementarity between categories of variables**

518 The ~~two first parts of our questionnaire were built in reaction to the existing~~ literature, showing that two types
519 of categories of variables seem to have an effect on private forest owners’ adaptation decisions: objective and
520 subjective variables.

521 Our results reveal that the variables that have a significant impact in Table 3, presenting the determinants of the
522 change in practices, and Table 6, presenting the determinants by adaptation strategy, are from both categories of
523 variables. Indeed, we observed that variables like forest area, region or management objective have a significant
524 impact on the propensity to adapt (objective variables), as well as variables like the perception of climate change
525 and the origin of climate change (subjective variables). In the same vein, significant variables from both
526 categories appeared in Table 6. This result suggests that the variables in the two categories are complementary to
527 explain adaptation decisions, including the strategy-by-strategy adaptation decision.

528 Our conclusion is in line with Van Gasteren and Zaccai (2015) who said that these two categories of variables
529 are complementary in the understanding of the private forest owner’s adaptation decision in Belgium, and
530 contrary to the results of Vulturius et al. (2018) who reported that only the “cognitive variables” (i.e., those
531 related to climate change) have a significant impact, whereas the socio-demographic variables do not in Sweden.
532 However, our results go a little bit further by revealing that this complementarity is also relevant when dealing
533 with adaptation strategies on an individual basis.

534 **6.3 Some limitations of the article and prospects for future research**

535 The article is based on a phone survey. In reality, such surveys face a number of problems. First, people may
536 mistrust calls from unknown individuals, especially in terms of security issues (Tourangeau 2004). Second,
537 innovations such as caller identification and answering machines make it possible to select the calls and to avoid
538 survey requests (Tuckel and O’Neill 2002). Third, the general increase in cellular phones instead of landlines is
539 another issue (Tourangeau 2004). Indeed, the phone numbers for landlines are easy to obtain and public, whereas
540 it is not the case for cellular phones. Concerning this last point, the CREDOC tried to contact owners through
541 landline and cellular phones. In our sample of 944 French private forest owners, 103 answered the questionnaire
542 via cellular phones and 841 through landline phones. The risk is an under-coverage bias (i.e., under-
543 representation of some sub-samples/population categories in the overall sample). This may be the case, for
544 example, if French private forest owners with only a cellular phone (younger ones?) were not well represented in
545 our sample. However, such an under-coverage is not relevant for our sample. We can try to find another way to
546 contact private forest owners in the future. For example, Web questionnaires are currently quite popular.
547 However, they may present problems for our population that is elderly. Indeed, only 35 owners are less than 44
548 years old, whereas 656 of the 944 respondents are between 45 and 65 years old, and 268 are over 65 years old.
549 This last segment of the population is not as connected. The risk is an over-representation of the younger
550 respondents in the sample. Since it is possible that different biases may impact the representativity of our sample
551 (and thus reduce the external validity of our results) in different ways, it is not easy to tell/assess/estimate to
552 what extent our results may be biased by such issues.

553 ~~The questionnaire focuses on objective and subjective questions independently from any theoretical economic~~
554 ~~framework.~~ An idea for future research would be to include behavioural items ~~that assume such a framework~~
555 in the questionnaire. For example, the literature has already shown that the forest owner’s attitude towards risk is a
556 ~~driver~~ determinant for the adaptation decision, whereas uncertainty aversion is not (Brunette et al. 2020), so that
557 including such an aversion measurement in the questionnaire may appear relevant. To do that, the multiple price
558 list methodology of Holt and Laury (2002) offers an interesting tool based on expected utility theory. Another
559 line of thought would be, for example, to consider a more sophisticated framework based on the cumulative
560 prospect theory (Kanheman and Tversky 1992). This theory considers psychological processes such as loss
561 aversion, subjective values of gains and losses and subjective probabilities. The experimental methodology based

562 on lottery choices and proposed by Tanaka et al. (2018) makes it possible to measure each of the parameters
563 associated with this theory. Introducing such behavioural considerations will bring new insights to this literature
564 on private forest owners' adaptation decisions. In addition, the complementarity or substitutability of these
565 behavioural variables with the categories of variables analysed in the current article may be interesting to focus
566 on.

567 The article is based on three adaptation strategies, whereas more than 30 have been suggested (Ogden and Innes
568 2009). However, it must be recalled that our objective is to deepen the analysis of the adaptation decision by
569 proposing to identify the determinants strategy-by-strategy. This means carrying out a regression per adaptation
570 strategy considered. Consequently, we focused on three strategies that are unanimous in the literature, in the
571 sense that their capacity to cope with climate change is recognised. Our results reveal that our intuition is true:
572 the determinants of the adaptation decision are different from one strategy to another. The analysis developed in
573 this article may then be reproduced for any adaptation strategy that appears interesting, especially to identify
574 relevant levers for public policy intervention.

575 The survey data mobilised in this study used a stratification sampling strategy so as to be representative in terms
576 of the forest area owned at the national level in order to provide results with an external validity. This choice
577 means that our results could be used for French forest adaptation policy design aimed at reaching a maximum
578 number of forest areas. However, it could be argued that reaching a maximum number of forest owners may also
579 matter, including the lowest decile of owners in terms of forest area owned. We focus on owners with at least 4
580 ha or about 76% of the private forest area. Indeed, in view of the limited public resources (human and financial),
581 the government has agreed to prioritise action for this population, targeting properties with the most favourable
582 criteria in terms of economic development. The choice was therefore to take this into account and focus on
583 owners with 4 ha or more.

584 Finally, some unobserved variables ~~that were not taken into account~~ may have an impact on the adaptation
585 decision. For example, we show that having a management document influences both the propensity to adapt and
586 the choice of the strategy. An interesting piece of information connected with the latter would be to know if the
587 forest owner has a certification or not. In addition, the questionnaire deals with risks, climate change and
588 adaptation, so that it may be interesting to know if the forest is insured or not. In particular, we wonder if
589 insurance contracts and adaptation strategies are complements or substitutes. This information should be
590 included in future questionnaires.

591 **7. Conclusion**

592 This paper focuses on the determinants of the French private forest owners' adaptation decisions through a
593 questionnaire. In particular, we tackled two main research questions about the determinants of the adaptation
594 decision ~~as a whole~~, and concerning the ~~drivers~~ determinants of the adoption of one strategy as opposed to
595 another. Our results reveal that both the objective and subjective variables ~~are complementary to~~ explain the
596 French private forest owners' adaptation decisions. Indeed, objective variables like gender, the owner's SPC, the
597 forest area, the revenue from hunting, the management document, the management objectives and the region
598 where the forest is located are on the same level as subjective variables such as the perception of climate change
599 and its impact, the way climate change manifests itself and its origin, to explain the probability to implement
600 adaptation strategies. In addition, we show that the determinants of the adaptation strategies are strategy-
601 dependent. For example, the implementation of the strategy *Early harvest* is influenced by the *SCPs Artisan* and
602 *Intermediary*, the management objective *Biodiversity* and *Leisure*, and possession of a management document.
603 The strategy *Irregular* is only impacted positively by the management document. The strategy *Thinning* is
604 affected by having perceived revenue in the last 12 months, the *SCP Employee*, the management objective
605 *Leisure*, and the anthropic origin of climate change. The fact that the determinants are dependent on the
606 adaptation strategy means that dealing with adaptation decisions in general may lead to wrong decisions, for
607 example, in terms of designing public policy to incentivise adaptation, and that the reflection should be
608 conducted at the level of the strategy itself. Consequently, a specific population associated with a specific
609 adaptation strategy should be targeted to increase adaptation policy implementation and efficiency.

610 These scientific results have practical implications. Indeed, the questionnaire was developed with forestry
611 organisations (advisors and managers), and the results are used to train new forestry advisors at the National
612 Centre of Forest Property. The results are presented to the technicians within the framework of the
613 accompaniment strategy of the forest owners. The key message is that expectations, needs and behaviours differ
614 from one owner to another and that it is important to take them into account in order to best assist the owners in

615 their efforts and provide advice that will allow them to remain interested and involved in the management of
616 their forest. Finally, the results also make it possible to design local public policies that incorporate our results
617 into their territorial reflection rather than a single policy, which is not the best option given the differences in the
618 profiles and expectations of the owners.

619

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785 **Appendix A. Description of the questionnaire**

786 Hello, I am [First and last name of the investigator] from CREDOC and I would like to speak to [First name Last
787 name of the contact provided], the person who takes care of the woodlands in the department [Department of the
788 contact provided] please. I am calling on behalf of the National Forest Property Centre and I would like to hear
789 your opinion on climate change and the impact it may have on your management practices and adaptation
790 strategies. This survey is anonymous and confidential. Do you agree to answer a few questions as a forest
791 owner?

792 This questionnaire lasts approximately 10 minutes and is composed of three parts.

793 For information, as part of our quality approach, this call can be recorded.

794 **PART 1: Objective variables**

795 Characteristics of the forest owner

796 1.1 Gender (variable *Gender* in Table 1).

797 Male

798 Female

799

800 1.2 How old are you? (variable *Age* in Table 1 recoded with three categories: < 44 years, 45-65 years, > 65
801 years).

802 Under 25

803 5-34 years

804 35-44 years

805 45-54 years

806 55-64 years

807 65-74 years

808 75 years and over

809

810 1.3 What is the highest level of diploma that you have obtained? (variable *Education* in Table 1 recoded with
811 five categories: No diploma, < A level, A level, 2 to 3 years after A level, Master).

812 No diploma

813 Certificate of primary studies

814 CAP, BEPC, BEP, college certificate

815 General, vocational or technical baccalaureate (A level)

816 BTS, DUT, DEUG (A level + 2 years)

817 License, master's degree, higher studies (A level + 3 years)

818 Master's, doctorate, engineer, higher studies (A level + 5 years and more)

819 Refused or no answer

820

821 1.4 What is/was your profession? (variable *SPC* in Table 1).

822 Farmer

823 Craftsman/Artisan

824 Superior (executive)

825 Intermediary

826 Employee

827 Worker

828 Never worked

829

830 Characteristics of the forest

831

832 1.5 Select the region where your forest is located (variable *Region* in Table 1).

833 Auvergne - Rhône-Alpes

834 Bourgogne -Franche-Comté

835 Bretagne - Pays de la Loire

836 Centre - Val de Loire - Ile de France

837 Corse - Provence-Alpes-Côte d'Azur - Occitanie

- 838 Grand Est
839 Hauts de France - Normandie
840 Nouvelle Aquitaine
841 None of these regions
842
843 1.6 What is the total forest area that you own? (variable *Area* in Table 1 recoded in four categories: 4-10 ha, 10-
844 25 ha, 25-100 ha, > 100 ha).
845 Less than 4 ha (in that case, the participant was thanked and the interview was stopped)
846 Between 4 and 10 ha
847 Between 10 and 25 ha
848 Between 25 and 100 ha
849 More than 100 ha
850 Don't know
851
852 1.7 Do your properties have one or more management documents for all or part of their forest area? (variable
853 *Manag_document* in Table 1).
854 Simple Management Plan ("Plan simple de gestion")
855 Management regulations ("Règlement type de gestion")
856 Code of good silvicultural practices ("Code de bonnes pratiques sylvicoles")
857
858 1.8 Personally, what interest(s) do you have in your forest? Is it for ... (variable *Objective* in Table 1).
859 Emotional attachment
860 Heritage
861 Fiscality / Tax system
862 Hunting
863 Timber production
864 Biodiversity preservation
865 Leisure
866
867 1.9 During the past 12 months, have you earned income from your timber thanks to...? (variable *Revenue_12*
868 *months* in Table 1).
869 Timber logging
870 Hunting rental
871 Another activity
872
873 **PART 2: Subjective variables**
874 Perception and cause of climate change
875
875 2.1 Do you think the climate is changing? (variable *Perception* in Table 2).
876 Yes
877 Somewhat yes
878 Somewhat not
879 Not at all
880 Don't know
881
881 2.2 Climate change depends on human actions? (variable *Anthropic* in Table 2).
882 Yes
883 Somewhat yes
884 Somewhat not
885 Not at all
886 Don't know
887
888 Observation and impact of climate change
889
889 2.3 What do you think will be the impact of climate change on your forest? Please choose only one of the
890 following proposals (variable *Impact* in Table 2).
891 Large impact
892 Small impact

- 893 No impact
 894 Don't know

895
 896 2.4 Would you say that this impact...? (variable *Timing* in Table 2).

- 897 Is already observable today
 898 Will be observed in 10 years
 899 Will be observed in 30 years
 900 Don't know

901
 902 2.5 Regarding the impact of the change on your forest, would you say that you are ...? (variable *Feeling* in Table 2).

- 903
 904 Very worried
 905 Not very worried
 906 Don't know

907
 908 2.6 In your opinion, climate change can be seen in your forest by...? (variable *Manifestation* in Table 2).

909

	Yes	No	Don' t know
910 More pronounced and more frequent droughts			
911 An increase in winter rains			
912 An increase in storms			
913 A reduction in frost periods			

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 920 **PART 3: Adaptation decisions towards climate change**

921 Changes of practices: strategies, triggers, motivations

922 3.1 In terms of forest management, would you say that...? (variable *Change_practices* in Table 3).

- 923 You have changed your practices for more than 5 years
 924 You have changed your practices over the past 5 years
 925 You plan to change your practices over the next 5 years
 926 You do not plan to change your practices in the next 5 years
 927 Don't know

928
 929 Questions for those having selected one of the first three possible answers in the previous question (changed
 930 your practices for more than 5 years, changed your practices over the past 5 years, plan to change your practices
 931 over the next 5 years).

932
 933 3.2 How do you plan to change or how have you already changed your practices? (variables *Thinning*, *Early harvest* and *Irregular* in Table 2).

934
 935

	Yes	No	Don' t know
936 Change the way you thin			
937 Harvest your trees earlier			
938 Harvest your trees later*			
939 Move towards irregular stands			
940 Move towards regular stands*			

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 946 * These two variables are not considered as adaptation strategies and are thus not included in our analysis.

947
 948 3.3 What triggered this change in practices? Is it...? (variable *Trigger* in Table 3).
 949

	Yes	No	Don' t know
Professional advice			
Advice from a loved one, a family member			
Specialised information in the forestry sector (review, conference)			
Renewal of the management document			

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 959 3.4 Did the following reasons motivate you to adapt your practices? (variable *Motivation* in Table 3).
 960

	Yes	No	Don' t know
Promote ecosystem services (water, carbon, biodiversity)			
Increase the capacity of your timber to resist climate change (resilience)			
Maintain or increase the productivity of your timber			
Limit potential damage			

966 Questions for those having selected “Do not plan to change” in the question related to change in practices.

967 No changes of practices: reasons for inaction, potential supports

968 3.5 Why do you not plan to change your forest management practices in the next 5 years? Is it because...?
 969 (variable *No change* in Table 3).
 970

	Yes	No	Don' t know
Your information is too limited			
The information available is contradictory			
You think you can still wait			
You have other priorities concerning the management of your forest			
You lack money or financial support			
Current regulations or administrative rules limit your means of action			
You are constrained by pressure from forest users (hikers, hunters)			

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 984 3.6 To better help you with your changes in practices, would you be interested in...? (variable *Support* in Table
 985 3).
 986

	Yes	No	Don' t know
Financial or tax assistance			
Technical assistance on climate change			
Scientific answers about the future climate of your region			
Specific training on climate change			

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 996 3.7 Regarding climate change, would the following incentives encourage you to modify your management
 997 practices in the next 5 years? (variable *Incentives to change* in Table 5).

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	Yes	No	Don' t know
Benefit from a diagnosis linked to climate change			
Take out insurance (storm, fire)			
Benefit from a diagnosis of the health status of your forest			
Benefit from the establishment of experimental plots to test new techniques			
Obtain financial assistance to implement adaptation strategies			

1010 The questionnaire is now finished. Do you have any comments or remarks to add?

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1033 **Appendix B. Results of the regression for Models (1) and (2).**

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1035 **Table B.1. The determinants of the change in practices for Models (1) and (2).**

	Model (1)	Model (2)
Area	0.00224 [*] (0.00117)	0.00211 [*] (0.00116)
Revenue_12 months	-0.0521 (0.288)	-0.0401 (0.290)
Gender	-1.407 ^{**} (0.427)	-1.026 ^{**} (0.440)
Farmer	4.229 ^{***} (0.253)	4.148 ^{***} (0.281)
Craftsman/Artisan	3.660 ^{***} (0.296)	3.629 ^{***} (0.327)
Superior	4.259 ^{***} (0.255)	4.209 ^{***} (0.285)
Intermediary	4.239 ^{***} (0.270)	4.160 ^{***} (0.309)
Employee	3.929 ^{***} (0.404)	3.868 ^{***} (0.408)
Worker	4.831 ^{***} (0.366)	4.750 ^{***} (0.385)
Manag_document	0.436 ^{**} (0.171)	0.450 ^{**} (0.185)
Revenue_logging	-0.565 ^{**} (0.267)	-0.530 [*] (0.272)
Revenue_hunting	-0.327 [*] (0.195)	-0.379 [*] (0.211)
Obj_Biodiversity	3.718 ^{***} (0.394)	3.909 ^{***} (0.486)
Obj_Heritage	4.067 ^{***} (0.694)	4.099 ^{***} (0.823)
Obj_Leisure	4.029 ^{***} (0.377)	4.209 ^{***} (0.487)
Obj_Timber	3.821 ^{***} (0.543)	4.006 ^{***} (0.626)
Impact	0.292 (0.188)	0.336 [*] (0.196)
More_drought	0.281 [*] (0.170)	0.271 (0.179)
Less_frost	-0.128 (0.126)	-0.175 (0.129)
More_winter_rain	-0.133 (0.143)	-0.152 (0.138)
Perception_Yes	0.398 ^{***} (0.129)	0.420 ^{***} (0.135)
Anthropic	-0.264 (0.174)	-0.318 [*] (0.175)
AUVERGNE-RHONE-ALPES		-0.685 ^{**} (0.272)
BOURGOGNE - FRANCHE-COMTE		-0.0379 (0.210)
BRETAGNE - PAYS de la LOIRE		-0.481 (0.300)
CENTRE - VAL de LOIRE - ILE de F		-0.871 ^{***} (0.330)
CORSE - PACA - OCCITANIE		-0.321 (0.261)
GRAND EST		-0.251 (0.304)
HAUTS de FRANCE - NORMANDIE		-0.164 (0.264)
Constant	-8.296 ^{***} (0.978)	-8.044 ^{***} (1.039)
Observations	628	628
Department-level clustering	Yes	Yes
Regional-level clustering	No	No
Adjusted R ²	0.1836	0.2101

Standard errors in parentheses; ^{*}p < 0.1; ^{**}p < 0.05; ^{***}p < 0.01

1036

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