On the Plurality of Environmental Regimes of Anticipation: Insights from Forest Science and Management

Antoine Dolez

Université Grenoble Alpes, CNRS, Sciences Po Grenoble ; Irstea Lessem, France / antoine.dolez@umrpacte.fr

Céline Granjou

Université Grenoble Alpes, Irstea Lessem / LISIS (Laboratoire interdisciplinaire sciences innovations sociétés), France

Séverine Louvel

Université Grenoble Alpes, CNRS, Sciences Po Grenoble, France

Abstract

In recent years, the social sciences have increasingly investigated ways in which futures are anticipated, fostered, and pre–empted. However, less attention has been given to how various predictive approaches inform different ways of acting in the present. Our article presents the results of an investigation into the current practices and agendas of forest scientists and managers in France. We first suggest how an anticipation of environmental futures is coming to the fore as an emerging field of expertise and practices in forest sciences, including predicting but also monitoring, preparing and adapting to projected futures. We then account for the co–existence of three 'micro–regimes' of anticipation combining a certain approach to the forest, a certain vision of the future, and a certain type of scientific predictive approach, including different anticipatory objectives, different modelling practices, and different interactions between research and management: i/ Adapting forestry to future climates; ii/ Predicting Future Tree Biology; iii/ Monitoring forests as indicators of climate change.

Keywords: regime of anticipation, climate change, forest science, foreknowledge

Introduction

In recent years, the social sciences have increasingly investigated the ways in which futures are anticipated, fostered, and pre–empted (Adams et al., 2009; Tavory and Eliasoph, 2013; Andersson and Duhautois, 2016; Coleman and Tutton, 2017; Granjou et al., 2017). A recent special issue in *the Sociological Review* is emblematic of the call for a new "engagement with and interrogation of the future in social sciences" (Coleman and Tutton, 2017: 441). It suggests "shifting the emphasis from looking into the future to looking at the future—that is, to engage with the future as an analytical object" (Coleman and Tutton, 2017: 441). This article is located at the crossroad between two streams of literature: first, the emerging scholarship which builds on cultural geography and anthropology research to question how ideas of the future inform actions in the present; second, the specific insights of Science and Technology Studies into the production and role of scientific forecasts and models in various academic fields and disciplines. In addressing how the anticipation of socio–environmental futures in a changing climate are coming to the fore as a new scientific and political agenda, this article aims to scrutinize the coexistence of various 'regimes' of predictive and anticipatory knowledge production and their embedment in several and partly conflicting politics of environmental anticipation. It follows Mike Michael's suggestion to account for the 'ecology of futures' at play in the intertwinement of both the 'Big Futures' at stake in broad societal and ecological narratives, and the 'Little Futures' pertaining to everyday social life and interactions (Michael, 2017). Our key question is: how does climate change, as the embodiment of a 'Big Future,' play out on the practices of forest modellers, and specifically on the way they anticipate the evolution of their research agendas and contributions to forest management? Our contribution shall account for the various Big and Little Futures and their relations at stake with the growing focus of environmental sciences on climate change anticipation.

Our contribution focuses on the case of forest science and forestry and unpacks how the anticipation of forest evolution in future climates is currently gaining ground in a rapidly growing field of research, expertise and management. Forest management is embedded within complex and interwoven issues of ecological sustainability and profitability. Its future prospects in a changing climate are highly uncertain and foster new concerns about how to anticipate the changing patterns of tree growth, species distribution, plant disease outbreak, forest productivity and economic profitability, as well as the overall adaptation of forestry practices. Forests are at the forefront of the "battle" against global change because they are often perceived as the "lungs of the world" and are thus a key factor in reducing carbon dioxide emissions. In this article, we document the way in which a growing range of forest scientists, field observers and managers are realigning their agendas, practices and goals around new anticipatory agendas and standards associated with the circulation of climate change projections and anticipatory concerns. By doing so, we shall highlight the plurality of anticipatory research agendas and predictive technologies that forest scientists have developed and how they are embedded within various visions of forest and forest futures as well as within contrasted relationships between research and forest management.

We will first present brief historical insights into the evolution of forests and forestry practices in France and emphasise how recent concerns about climate change have fostered new anticipatory agendas and practices in forest science and management. We shall describe how climate change topics and concerns are transforming forest science organisations, collaborations and material infrastructures of knowledge, including practices of data production, and how this process of 'climatisation' (Aykut et al.., 2017) involves increasing exchanges and collaborations between forest science, ecology and climate science and the models that were previously developed in isolation from each of those fields. Then we shall document the co–existence of three micro–regimes of anticipation in the case of French forest science and management and eventually account for their tensions and relations. Each of these micro–regimes combines a vision of the future with an approach to the forest, including a certain type of scientific predictive approach associated with modelling practices. In particular, we will discuss Aradau and Van Münster's (2013) and Amoore's (2013) idea that the rise of future–oriented knowledge agendas destabilises pre–existing scientific approaches based on the interpretation of past data and requires disruptive epistemology and practices. We argue that the future does not necessarily disrupt previous epistemic practices and organisations; instead, the production of foreknowledge is embedded in various, situated visions of the specific future and knowledge.

Empirical and theoretical background

The case of French forest science and management

This article is based on a sociological investigation into forest science and management in France, including about 30 interviews with forest scientists, forest managers and field correspondents and backed up with the reading of forest science articles, administrative literature and institutional websites. The forest scientists we interviewed are members of the main disciplines involved in forest science (mostly ecology, but also biology, genetics and computer science) and various research institutions, including France's National Center for Scientific Research (CNRS), the Research Institute of Science and Technology for Environment and Agriculture (IRSTEA) and the National Institute for Agriculture Research (INRA). Semi–structured interviews were focused on scientists' professional trajectory and career, their vision of the scientific field including modelling and predicting the evolution of forests, and their vision of the future and the type of knowledge they build on it. In the case of forest managers, interviews included a focus on management practices and potential uses of models and simulations.

What makes France an interesting example of the development of various predictive and anticipatory regimes regarding forests and climate change? It is mostly the strong interdependence between forest science and forest management which can be traced back to the French historical tradition of centralised forest science and forest management, linked to the high economic and social importance of forests to the nation (Decocq et al., 2016). Today forests cover around 30% of the French mainland with 75% being private forests and 25% public forests, a third of which are managed by the National Forests Office (ONF) while the rest is owned by local councils. The ONF, which employs around 10,000 people today, was created in 1964 and is in charge of wood production, forest protection and tourism. The Research and Development department of the ONF promotes exchanges, collaborations and knowledge transfers between forest science and forestry.

Theoretical background: 'climatisation' and the 'micro–regimes' of anticipation

The STS literature has long addressed the production of predictive knowledge and the particular status and role of predictions in science–policy interface (in systems dynamics: Bloomfield, 1986; economy: Collins and Pinch, 1996 and geosciences: Sarewitz et al., 2000; Dahan–Dalmedico, 2006; Edwards, 2010). STS scholars have notably criticized the "quest for a scientifically legitimated view of the future" through the development of scientific predictive models (Sarewitz et al., 2000: 367). Much attention has been given to why predictive models do not or cannot produce accurate predictions (Collins and Pinch, 1998) and how those predictions should be communicated, received and used (Sarewitz et al., 2000). Recent STS and post–ANT scholarship also insist on the performative role of models, scenarios and simulations and their effects on shaping the reality, for instance, how economics shape and perform economy (Callon, 1998; Mackenzie et al., 2007) and more broadly how differing scientific models and approaches shape various "ontologies" (Mol, 2002; Law and Mol, 2002), as they encompass several different ways of knowing and intervening upon it. Our point, however, is concerned less with these ontological politics than with the embedment of predictive models within various and partly conflicting politics of environmental anticipation.

STS scholars started scrutinizing the internal plurality of predictive approaches and models in the case of glaciology (yet see: Skrydstrup, 2017). However, less attention has been given to how differing predictive approaches inform various ways of acting in the present. Recent literature examined the investigation of official counter–terrorism programmes and practices and elaborated on the expansion of a 'politics of possibility' that aims "not to prevent the playing out of a particular course of events on the basis of past data tracked forward into probable futures but to pre–empt an unfolding and emergent event in relation to an array of possible projected futures" (Amoore, 2013: 9). Aradau and van Münster also depicted an all–encompassing 'Regime of Anticipation' including the development of a new "conjectural episteme" in which imagination mostly replaces the use of past data sets to attempt to make the future "knowable" (Aradau and van Münster, 2011).

We argue that those theorisations do not properly account for how scientists, experts, policymakers and managers associate practices, infrastructures and imaginaries to anticipate the 'not yet'. We propose to develop the notion of 'micro–regime' of anticipation in order to empirically account for those various assemblages and their mutual tensions. We further criticize the idea there is only one Science (Knorr–Cetina, 1999) by unpacking the diversity of foreknowledge and predictive models in the case of forests and climate change. Our notion of 'micro–regimes' of anticipation is inspired by Pestre's approach to the micro–historical embedment of the production of knowledge into socio–economic regulation (Pestre, 2003) and departs from descriptions of the historical development and succession of broad regimes or 'styles of knowing or reasoning' from past to present (Hacking, 1994; Kwa, 2011). While Pestre's notion of 'regime of knowledge' puts forward the interactions between science, politics and society on a macro–social level, the notion of 'micro–regimes' is located at the smaller level of mundane research agendas and practices (Shinn, 1999). 'Micro–regimes' of anticipation are ways of negotiating the co–production of 'Big Futures' (here embodied in narratives of climate change and its impacts on forests) together with 'Little Futures', which pertain to routine research practices and interactions, including developing models, collaborations and projects, etc. (Michael, 2017).

The construction of climate change as a global concern and expertise has been extensively documented (see in particular: Jasanoff and de Martello, 2004; Edwards, 2010). However, research is only emerging on how climate change issues and concerns are now reframed as local concerns in a wide range of sectors and activities whose practices, communities, jobs and identities are being transformed and re–aligned toward anticipatory objectives which relate to various situated activities and agendas. Sociologists Aykut, Foyer and Morena (2017) proposed the notion of 'climatisation' to depict this multi–level and highly contextual process of re–alignment of a range of agendas and practices with climate issues. We argue that 'climatisation' importantly involves the realignment of knowledge practices toward anticipatory objectives and agendas, including predicting but also monitoring, preparing and adapting to projected futures. We shall describe the 'climatisation' of forest science organisations, collaborations and material infrastructures of knowledge, including practices of data production and modelling, and how this involves increasing exchanges and collaborations between forest science, ecology and climate science—as well as between the models that were previously developed in isolation in each of those fields. Eventually, we shall document the coexistence of different competing micro–regimes of anticipation that forest scientists and managers deploy and how those anticipatory micro–regimes are embedded in various (and partly competing) processes of research agenda setting and environmental issue framing.

Anticipatory pluralism in forests science and management

The 'climatisation' of forest science and management

Almost all the forest scientists and managers we met spontaneously referred to climate change in their answers when asked about on–going changes in their research agenda and practices, indicating that aligning one's research and agenda with climate change had become necessary in order to attract funding. Beyond the rhetorical reference to climate change, forest scientists and practitioners also suggested that they were now confronted with very practical questions related to the anticipation of forest growth and productivity under future climates, such as: How will rising temperatures, soil acidification and water scarcity influence tree growth and forest species composition? Which species will be the most resilient to future droughts, heat waves or storms? When will be the best moment to harvest timber productions? Our field work thus confirms bibliometric analyses which suggest that climate change has become a central topic in forest science, along with others such as "carbon dioxide" and "adaptation" (Aleixandre–Benavent et al., 2017). However, we found that 'climatisation' (Aykut et al.., 2017) occurred not only at a discursive level—meaning the integration of the topic of climate change into forest science agendas and discourses—but also within organisations, collaborations and material infrastructures of knowledge. For instance, the ONF's R&D department was reorganised in 2005 along five topics including climate change. A range of new research and management networks were created in order to address the impact of climate change on forests and forestry, such as the GIP ECOFOR ("ECOsystèmes FORestiers") which was founded in 1993 and has been supporting research on forests and climate change since the beginning of the 2000s, including research on the future distribution of French forests in a changing climate[1]. Forest scientists and managers also started implementing new climate–related data collection and new collaborative arrangements around climate data sharing and use, for instance within the network of forest observation sites called RENECOFOR, initially created in relation to concerns over the effects of acid rain on forests. In 2012, RENECOFOR was also integrated into a Long–term Environmental Research Monitoring and Testing System (SOERE), whose goal is to produce data on the "System Earth" dynamic, illustrating how the collection of forest and climate related data becomes embedded within new collaboration arrangements between a broad range of disciplines such as ecology, forest science, genetics and population biology.

The 'climatisation' of forest science and management also fostered the development of new methods for modelling forest growth and making decisions regarding which tree species to choose and when to fell trees for timber production. Such decisions were first made on the basis of the production quotas, which calculate the annual growth of one species in a particular place, and served as decision guidelines for when to fell the trees and which tree species will grow faster. From the mid–1980s, forest engineers have developed empirical models in order to predict the timber productivity of a particular forest in a constant environment, including soil and climate. Those models are fuelled by long–term data produced by the National Forest Inventory. The 'climatisation' of forest science and management has triggered the convergence of empirical, forestry–oriented models with other types of models that have long developed in isolation from forestry concerns and practices, i.e. process–based, statistical models (Korzukhin et al., 1996; Adams et al., 2013). The latter models have been developed in biology and in ecology since the beginning of the twentieth century in the wake of the equations of Lotka–Volterra (Leslie, 1948). They aim to understand simple or fundamental biological processes such as photosynthesis (Farquhar et al., 1980) or carbon allocation and to translate them into equations. These equations can then fuel a computer program that simulates "virtual experiments" (Legay, 1997).

These two types of models have long been developed in isolation from each other, as forestry–oriented models were taught in forestry schools and process–based models in ecology and biology master's degrees. In the early 2000s, growing interest in understanding the evolution of forests in the context of climate change led to the development of new models that blur that distinction by mixing the characteristics and objectives of the two former categories of models, as a forest scientist explained:

> Process–based models attempted to summarise ecosystem functioning without any predictive objective […] however, with climate change issues we discovered that this dichotomy did not work anymore […].We understood that empirical models should also explicitly integrate climatic data into their architecture and equations; on the other hand, process–based models should also address prediction and applications…

As a result, many of the forest scientists we interviewed use climate scenarios designed by the IPCC and other climate–oriented research institutions (such as Météo–France which develops climate projections with great precision at the local level in France) and integrate them into pre–existing forestry–oriented models in order to simulate the potential growth of trees in a changing climate.

On the other hand, while climate projections are increasingly used and integrated into forest models, forest models are also increasingly integrated into climate change modelling which tends to become more and more integrative and biological (while initial climate models relied on atmosphere physics and chemistry only). Science historian Amy Dahan–Dalmedico accounted for how climate change models shifted in the 1990s from a focus on the atmosphere to a broader focus on 'Earth systems' integrating oceans and terrestrial surfaces, i.e. vegetation and forests (Dahan–Dalmedico, 2010). As a result, not only do forests scientists use climatic models in forest research, but forests models also fuel broader climate models that simulate the interactions between the atmosphere and the biosphere. For instance, the Laboratory of Climate and Environmental Sciences in Paris–Saclay, which hosts climate scientists actively involved in the IPCC, has developed the ORCHIDEE model, which simulates the role of tree development and life cycles in carbon flows in the biosphere, including the ORCHIDEE–FM submodel which integrates the effects of various forestry strategies on carbon cycle.

The 'climatisation' of forest sciences thus involves increasing exchanges and collaborations between forest science, ecology and climate science and the models that were previously developed in isolation in each of those fields. Yet far from an all–encompassing alignment towards a unique anticipatory "episteme" (Aradau and van Münster, 2013), our fieldwork also points to the co–existence of a plurality of research agendas dedicated to anticipating the future of forests under a changing climate. These research agendas differ in two ways: they develop forest–driven vs. climate–driven science on one hand. On the other hand, they handle forestry–oriented versus ecological and biological process–based research.

Three 'micro–regimes' of anticipation

This section describes three 'micro–regimes' of anticipation which became apparent during our fieldwork. Each of these combines three dimensions: a certain vision of the forest, a certain idea of the future, and a certain type of scientific predictive approach, including different anticipatory objectives, different types of models and modelling practices, and different interactions between research and management (see Table 1). The three 'micro–regimes' encompass actors' various views of the type of knowledge that matters for forest and forest management, including certain visions of the extent to which the future disrupts past and present scientific practices and technologies.

Following the analytical distinction introduced by Mike Michael (2017), each 'micro–regime' of anticipation shapes and performs both "Big" and "Little" futures including ecological futures (climate change), economic futures (forestry evolution), and academic and scientific futures (research agenda setting, maintenance or creation of collaborations, publication writing, etc.). These are ways of negotiating their coexistence and potential tensions at various levels.

First 'micro–regime': Adapting forestry to future climates

In the first 'micro–regime' of anticipation, researchers and managers seek to predict the composition and geographical distribution of forest and forest socio–ecologies in future climates. Their scientific practices are those traditionally used in forest science and engineering. They assess timber stocks using forest inventories and maps and they construct statistical models that build on correlations between a wide range of ecological, geophysical and socio–economic parameters in order to estimate the productivity of future forests, to write guidelines and design forests policies. That foreknowledge is meant to help produce guidelines for present and future forestry practices and to contribute to forestry economic planning and adaptation. The vision of the future focuses on securing future forestry activities. Forests are considered to be anthropogenic, managed socio–ecosystems.

The anticipatory logic of this 'micro–regime' is to improve forestry strategies by taking into account climate change. What matters is that the model can be applied in order to guide forestry choices. A key objective is to identify the forest practitioners' leverage actions to secure forestry in a changing climate. This first 'micro–regime' thus gathers forest scientists and engineers from various research institutes (IRSTEA, INRA), the R&D department of the National Forest office, and members of forest research networks such as GIP ECOFOR. Close relations and collaborations between forests scientists, managers and decision–makers are an

Table 1: Three 'micro–regimes' of anticipation.

	Adapting forestry to future climates	Predicting Future Tree Biology	Monitoring forests as indicators of climate change
1. Vision of forests	Forests are considered to be socio–ecosystems.	Forests are considered to be a functional system governed by ecological processes.	Forests are considered to be an observatory of the evolution of climate change.
2. Visions of the future	The future is viewed on past and present trends.	The future is disruptive. Researchers and managers assume that studying fundamental ecological processes in a changing climate is essentially different from studying them under stable climatic conditions.	The future becomes palpable and knowable, and thus governable.
3. Type of scientific predictive practices			
3–i/ Anticipatory logic and objectives	Adapting forestry strategies in a changing climate	Understanding the ecological processes at stake in the evolution of forests (such as carbon flows and water scarcity)	Producing indicators of climate change, assessing and mapping its evolution
3–ii/ Modelling practices	Statistical "meta–models" that aggregate a broad range of ecological, social and economic variables	Simple ecological and process–based models	Simple model illustrating the causal relation between the chosen indicator and climate change
3–iii/ Interactions between research and management	Strong collaborations between forest science and forest management: data sharing, collaboration in research projects, and co–production of forestry guidelines	Researchers contribute as experts to biodiversity and nature conservation international and national organizations	Contributions to the French Ministry of Environment; Co–construction of indicators between forest researchers and managers.

essential characteristic of this micro–regime; they result both from collaborations and from individual mobility between organizations dedicated to forest management (such as the National Forest Office) and organisations dedicated to scientific research and to producing technical support and advice for foresters (such as INRA and IRSTEA).

The models at stake in this first 'micro–regime' are constructed and calibrated using a large amount of data collected during forest inventories and by research teams. They integrate both ecological variables (i.e. tree growth and mortality, forests composition, light interception) and socioeconomic variables (i.e. forestry strategies, expected timber stock). The researchers' objective is to run multiple simulations with different models to foresee the consequences of their potential forestry's strategies. As a result, models tend to accumulate and integrate an ever increasing number and variety of variables, as suggested for instance by the case of the SAMSARA model, a tree–growth model whose many versions were developed over time in order to achieve the integration of an ever wider range of processes, including wind damage (Ancelin et al., 2004), colonisation processes (Cordonnier et al., 2006), intraspecific competitions (Vieilledent et al., 2010) and biodiversity's stock, ecosystems services (Courbaud et al. 2017; Lafond et al. 2017)[2] and climatic parameters (while the model was initially designed under a constant climate) (Lagarrigues, 2016). The implementation of the CAPSIS modelling platform in 1998 (Dufour–Kowalski et al., 2012) also illustrates the trend towards the increase in the number of variables as the platform integrates about 70 different forest models in only one simulation software and makes it possible to run all of them together in order to predict how any given variable will react in a changing climate. An engineer in charge of CAPSIS told us:

> In CAPSIS, we have tree–growth models. These models grow trees; they create virtual forests. Then, you can add other models to them, for example, timber quality models or risk models, to address how the forest may resist wind storms (…) or economic models. All those second–level models can be added to CAPSIS tree–growth models in the same simulator.

Accordingly, the models used in the first 'micro–regimes' must be user–friendly—the calculation speed is a key element in this: "If it takes too much time to set up the data and run the simulation, it is off–putting. It is a beautiful theoretical tool but in practice it is useless" (Forests modeller). When we asked modellers and managers about potential future improvements of the models, all of them referred to an increase in the calculation's speed. The development of remote–sensing using LIDAR (Laser Imaging Detection and Ranging) is also expected to help collect ever larger amounts of data to fuel the models with the idea that scientific progress meant both more and more past and present data for more and more anticipative models. Accordingly, the first micro–regime does not focus on knowing the ecological processes but relies on statistical methods applied to big datasets to find correlations between climatic, biological and socio–economic information. Modellers use ecological processes such as tools to parameterise the models; however, producing knowledge on those processes is not part of their objectives:

> I'm not interested in ecology as a science. I take an interest in forest as a socio–ecosystem; it's my point of view, but I can't avoid ecology because it is one of the analytical and theoretical sciences I use to study forests. (Modeller working at the National Forest Office and INRA)

As a result, in the first micro–regime, the future is mostly deduced from past and current trends detected by using ever bigger sets of data. As a modeller reported: "Yes, I'm interested in the future, but most of the time, it is the past that I study." However, both modellers and managers are aware that the future may destabilize and disrupt past and present trends. They address the disruptive character of the future by accumulating models and variables—thus, rising computing power—and by developing new statistical methods, such as the Bayesian approach, which "aims to artificially break with the linear structure of time", a modeller said. These tools are standardized for example in *R*-packages (Jabot et al., 2013).

Referring to Michael's distinction between 'Big' and 'Little' futures (Michael, 2017), one could say that the Big Future envisioned by forest researchers and managers in this micro–regime is about securing forestry under a changing climate, while the Little Futures that are at play in the everyday life of forest research teams include:

- Developing ever more sophisticated and integrative statistical models that take into account an increasing range of parameters in order to produce forestry guidelines;
- Developing new technologies of data–collection, including remote–sensing technologies, in order to improve the quantity and quality of the data available;
- Reforming forest management and the institutions in charge of it in order to secure future forestry under a changing climate.

Second 'micro–regime': anticipating future tree biology

In the second 'micro–regime' of anticipation, researchers aim to understand and predict the evolution of forest ecological functioning by modelling how future climates—including extreme events such as severe droughts (Estiarte et al., 2016; Lempereur et al., 2017)—will affect the way trees use an array of resources (water, carbon, nutrients, light). This 'micro–regime' is no longer related to utilitarian objectives (i.e. designing forestry practical guidelines and economic planning). Instead, it should be understood in the more environmentalist perspective of understanding the ecological processes at stake in the evolution of forests under future climates. Some of them contribute as experts to biodiversity and nature conservation organizations, such as the Intergovernmental Platform on Biodiversity and Ecosystem Services or the French Foundation for Biodiversity Research. This micro–regime aggregates what scientists call "simple" process–based biological modelling, *in natura* experiments and ecological theories.

Ecologists and modellers involved in this 'micro–regime' tackle ecological questions such as: What is the link between diversity and stability? (Morin et al., 2011) How resilient is the ecosystem when faced with scarcity? Which function of the ecosystems will be the first to react to a changing climate (Gustafson et al., 2015)? Compared with the first 'micro–regime', ecology—especially functional ecology—plays a central role and is no longer merely considered a tool. For the researchers involved in this 'micro–regime', understanding the dynamic of forest ecosystems is an opportunity to understand fundamental ecological processes at stake, such as photosynthesis or the allocation of carbon between plants (Gea–Izquierdo et al., 2015), atmosphere and soil and between different parts of the plants, as explained by a forest scientist whom we interviewed:

> I'm not interested in the holm oak, but rather in… how forests respond to scarcity (…) In that case, we worked on the holm oak. Yet what matters for us is really the functioning, the functional aspects in terms of ecosystems, carbon flow, growth, primary productivity …

The anticipatory logic of this second 'micro–regime' addresses climate change as a disruptive event that forces forest modellers to renew their practices and develop collaborations with experimenters and functional ecologists. Researchers assume that studying fundamental ecological processes in a changing climate is essentially different from studying them under stable climatic conditions. Climate change is thought to trigger environmental conditions that will be essentially different from the environmental past and present, as one of the forest ecologists we met explained:

> As soon as we have something calibrated to the present… I mean, it is tempting to apply the model to the future and to see what will happen. But the question is: Is the knowledge of the system in the current climate sufficient to be applied to future scenarios, including extreme conditions? … I want to know whether my little model, which is calibrated to current conditions, using 10 years of data collection, could be applied to extreme events, such as a six–month water shortage. That is to say, things that you have rarely or never observed so far…

In a similar way, another forest ecologist explained that "modelling is not interesting when everything is all right," meaning he did not expect simulation models to make a linear business–as–usual prediction based on past data, but instead to be able to integrate future extreme events and to deal with the disruptive nature of climate future. With that goal, ecologists and modellers seek to capture the non–linear responses of ecosystems by developing both modelling and *in natura* experimentation (Perez–Ramos et al., 2010). For example, the same ecologist developed an experimentation consisting of excluding rain for a few months (using artificial covers to protect plants from the rain) in order to enrich his model:

> It has allowed me to add a few modules that were not in the first version of the model. The model calibrated to the current climate works up to a precise threshold, and once this threshold is crossed, you have to add a [new] module... it is something that my models initially did not take into account, and now I am developing it in order to simulate the non–linear relationship between water scarcity and fire risk.

Field experimentations are meant to help set and observe the possible future climatic conditions and their impacts on trees and forests. The development of experimentations on the effects of climate change on ecosystem functioning is emblematic of what some interviewed forest ecologists called an "experimental turn" that dates back to the mid–2000s. Yet some forest ecologists whom we interviewed emphasized the difficulty or even impossibility of conducting experiments on trees in completely controlled 'live labs' such as the controlled experimental enclosures called 'ecotrons' that have been constructed in France in the 2000s (and elsewhere in the world[3]) because of scale issues (ecotrons are not designed to host more than two–meter–high plants) (Granjou and Walker, 2016). As a consequence, they have developed field experiments that consist of conditioning gas concentrations or simulating climates (for instance, droughts) in the field by using, for instance, flux towers which enrich the air in CO2 and measure gas concentration and temperature at the bottom and at the top of the studied trees (Misson et al., 2010).

In this 'micro–regime', relationships between researchers and managers are less close than in the first micro–regime. This is partly because researchers would rather belong to laboratories and centres favouring fundamental research over applied research (such as the French National Center for Scientific Research CNRS)—even though the institutions of belonging do not systematically determine the development of applied versus fundamental research by their members. This is also because when researchers produce knowledge on ecological processes, it makes it difficult for them to connect to forest management issues and concerns, as a forest scientists working at the CNRS (Center for Evolutionary and Functional Ecology) explained:

> Relationships with managers remain difficult because we face a cultural issue. I mean, we consider forests as an ecosystem. It is an ecological point of view, and they consider forests as a production means, something cultivated. In foresters' minds, the forest is something we cultivate, and it is not a natural ecosystem. They are concerned about productivity, plantations or species selection and not really about how trees use what they have and how they manage available resources. (…) [W]e are definitely not on it.

In the second 'micro–regime', the Big Future is about anticipating future tree biology under a changing climate. This is enacted through 'Little Futures' that include improving simple models of tree biology, developing *in natura* experimental infrastructures, improving the linkages between process–based models and field experimentations, and contributing to biodiversity conservation and management organizations.

Third 'micro–regime': Monitoring forests as indicators of climate change

In the third 'micro–regime' of anticipation, researchers and managers consider the evolution of forests as a case–study for observing and predicting the evolution of climate and its broader impacts on ecosystems and society. They monitor forest fauna and flora, collect field data and combine the data with population biology models and laboratory experiments in order to develop indicators of the growing intensity and impacts of climate change. While the models used in this 'micro–regime' are meant to be simple models, like in the second 'micro–regime', the ultimate objective is not to understand basic biology but to represent the state and evolution of climate in order to inform policy–makers, in particular from the French Ministry of Environment, in order to design environmental and climate policies. This 'micro–regime' mostly builds on scientific results produced by the first two 'micro–regimes' (as, for instance, the budburst indicator which builds on the modelling of the various steps of plant growth and life cycle, Chuine, 2000). Eventually the third micro–regime differs from the first two as it does not tackle "the forest" *per se* but focuses on climate change and only makes use of the forest as a proxy to make climate change visible: the very object of anticipation differs between the first two 'micro–regimes' and the third one.

In the third 'micro–regime' of anticipation, researchers from the National Institute for Agriculture Research (INRA) and field correspondents from the ONF monitor and record forest data in order to document and assess the ongoing evolution of climate. Here, forest data are useful to the extent that they can be directly linked to climate change, such as, for instance, shifting budburst dates which are thought to be caused by warmer springs (Chuine and Cour, 1999). Forest data are conceived as climate change indicators when the relation between the indicator and climate change is considered to be simple and almost causal. The ONERC (National Observatory on the Effects of Global Warming), which is part of the French Ministry of Environment, defines an indicator as "information tied to a phenomenon [that shows] its evolution through time in an objective way."An indicator is like a thermometer: "As the body's temperature gives a hint about a patient's health, climate change indicators tell us about the Earth's state" (National Observatory on the Effects of Global Warming, 2010). As in the first 'micro–regime', indicators are conveyed to both forest managers and politicians to inform them of the evolution of climate change and allow for designing appropriate forest policies. Therefore, the form and aesthetic of the indicator are central because this is the way in which climate change is made visible and palpable. This 'micro–regime' gathers scientists from a broad range of disciplines such as genetics, population biology or entomology. Researchers produce indicators and information for the French Ministry of Environment that are meant to be collective reference landmarks on the intensity and impacts of climate change for policy–making.

One of the best–known indicators in France is the pine processionary caterpillar (Rossi et al., 2015), which is a forest parasite that causes tree death and health problems inhumans and animals. Pine processionary caterpillars have very stinging hairs that can cause skin problems to both humans and pets. Researchers initially started studying this insect because it is one of the most dangerous European parasites for forests as they eat pine needles and cause the tree to die. The progressive change of focus in the research devoted to the caterpillar, from pest to climate indicator, gives another example of the 'climatisation' of forest research agendas and practices (Roques, 2015). Since the creation of the ONERC in 2001, the caterpillar has indeed become a central indicator for assessing the evolution of climate once the relation of its growing numbers and shifting geographic distribution with climatic parameters was established in the literature. The processionary caterpillar was thus progressively built as a "reference model" meaning "a model of response to climate change" (to quote a forest researcher whom we interviewed). This latter notion of 'model' has some similarities with the way biologists use 'model organisms' such as mice or E. Coli in order to study fundamental biological mechanisms. While the idea in both cases is to focus on a 'simplified case' in order to understand a more complicated general issue, in our third 'micro–regime', however, forest scientists' ultimate goal is not to study basic ecological mechanisms (like in the second micro–regime) but to deduce trends of on–going climate change from certain characteristics of forest evolution. Accordingly, in a similar manner to the statistical models of the first 'micro–regime', researchers and managers expect to be able to collect ever more field data in order to improve the accuracy of climate change indicators.

Results are presented under the form of a map that shows the past, present and future progression of the "colonisation front" of the caterpillar. Therefore, the anticipatory logic at stake here puts past, present and future in linear succession in order to make climate change visible and palpable. Compared to the two other 'micro–regimes', the focus of the third micro–regime is on raising the alarm and alerting managers and decision–makers on the progress of climate change with the idea that the future is already here and we have to act now in order to adapt to it. Accordingly, the vision of the future is both in continuity with past and present at the level of scientific and modelling practices that use past data of caterpillar populations and distribution, and disruptive at the political level because it invites both managers and politicians to act now in order to adapt to the future.

In this 'micro–regime', Big Futures are about assessing the progress of on–going climate change and alerting decision–makers, involving Little Futures that include finding ever more accurate and simple–to–use indicators of climate change and their impacts, collecting ever more data to fuel indicator levels and maps, and fostering policy changes and adaptation strategies.

Relations and interactions between the three micro–regimes

Our inquiry accounted for the co–existence of three 'micro–regimes' of anticipation that seek to anticipate the evolution of forests under a changing climate. We found that researchers in the three micro–regimes belonged to different scientific institutions and published in different scientific journals, suggesting that the three 'micro–regimes' operate in relative isolation from each other. The first micro–regime spans across traditional agriculture and forest science and management institutions such as INRA, IRSTEA or ONF, whereas the second one unfolds in more basic research institutions such as CNRS. The third 'micro–regime' involves both traditional forest research and management institutions (INRA, IRSTEA, and ONF) and policy–making institutions (the French Ministry of the Environment). Bibliometric analysis also shows that researchers in the first 'micro–regime' publish in academic forest science and management such as, for example, *Annals of Forest Science* or *Forest ecology and management*, while researchers in the second 'micro–regime' publish in ecology and global change journals such as *Global Change Biology* or *Ecological Letters*. In the third 'micro–regime', they publish both in genetics or population biology journals such as *Journal of Applied Entomology* or *Insect Biochemistry and Molecular Biology*; they also publish papers in more applied forest management journals and reports for the French Ministry of the Environment.

However, certain scientists moved from the first to the second 'micro–regime' as, after being initially trained in forestry schools—such as the National School of Water and Forests in Nancy—they found positions in ecology laboratories in research institutions such as CNRS. This is the case of a forest ecologist trained in the French National School of Forestry, who now develops fundamental ecological research into tree competition, which falls under the second 'micro–regime'. Other researchers also moved from the first to the second 'micro–regime' as they became more aware of the uncertainties and limits related to running big correlative models. This is, for instance, the case of a forest modeller who works on the evolution of fire risks in a changing climate. While his research was initially focused on developing correlative and statistical models, he progressively became convinced that he could not extrapolate future conditions by relying solely on past and current data, because the system would not have the same behaviour if the extreme events started to become more frequent. As a result, he stopped making predictions and started developing research on more basic processes. Another modeller started his scientific career by working on trees' large–scale distribution in various forests and using correlative models and inventory data sets—a research activity that falls under the first micro–regime of anticipation. However, during his career, his interest shifted to theoretical ecological processes such as the functioning and evolution of the diverse tree species in a given forest and he began studying the general link between an ecosystem's diversity and its stability, then meeting the approaches favoured under the second 'micro–regime'.

A number of researchers also criticized the first 'micro–regime' as 'fashionable' but not robust enough in scientific terms. They meant that too many variables and data put together as models are run in order to obtain long–term previsions with little attention to the precise biological mechanisms and diversity at stake. Importantly, while researchers in the first 'micro–regime' construct the future as the follow–up to both the past and the present, researchers in the second 'micro–regime' consider the future to be disruptive. Therefore, they doubt models and simulation based on past data series to be able to properly predict the future. They think that there are things and rules that just cannot be known in advance, also implying a different vision of which sort of knowledge is worth developing, as the head of an important research centre in ecology in France explained:

> I'm not able to model the rules of carbon allocation in a tree: how much carbon is allocated to the roots, to the trunk, or some other thing? I'm not able to give an equation and say: This is how it works. Hence, I'm unable to make a prediction. Anyone who predicts the forest productivity or the timber stock in the 2100s if rainfall drops by 30% relies on current carbon allocation rules. We know that these rules will change, but we don't know how to model it. It doesn't prevent us from making predictions, but what is their validity? I don't know.

He also suggested that the recent development of the first 'micro–regime' was strongly driven and supported by managers and decision–makers' high expectations in the capacity of forest science to produce long–term predictions on the future of forestry. In particular, he criticised the increasing development of integrative, statistical models producing maps of species distribution at very long term, for instance, 2100. To him, these correlative statistical models produce "beautiful maps" but fail to address fundamental scientific issues such as how ecosystem functioning would be impacted by a changing climate. He argued that modelling practices should not be taken as a scientific result *per se*: "So, we have a model, and that's it. We fuel it with anything and it outputs something. A model always gives you some result." Instead, models should support the search for scientific answers to problems regarding ecological mechanisms.

Researchers working under the second 'micro–regime' thought that they were "closer to the biological reality" by developing models that take into account a very limited set of variables in a very precise manner:

> I reduce everything to one parameter: quality Q. But in fact, the precision with which I calibrate my "black box" takes into account the chemical diversity of the species... while the big categories [used in statistical models] do not take it inaccount. So, they told me that my research is a "black box," but it is *their* research that is a "black box"! (A forest ecologist)

The friction between the first and second 'micro–regimes' is thus linked to their visions of which sort of scientific advancement matters, i.e. to different visions of what future knowledge agendas are worth developing and to different ideas of what "good" forest science is.

We also found a range of cases of combination and collaboration between researchers from the first and second 'micro–regimes' of anticipation, such as in the case of the CarboFor research project (2002 – 2004) (Loustau, 2004). The CarboFor project was the first French scientific project to develop integrative statistical models based on IPCC scenarios in order to foresee the impacts of climate change on the distribution of trees over the long term. As these models progressively appeared as being not precise enough, a second research project, Qdiv, aimed to improve the representation of forest ecological functioning. This project led to comparing and integrating the correlative models developed in the first micro–regime (such as BIOMOD: Thuiller, 2003) and the process–based models developed in the second micro–regime (such as Phenofit: Chuine, 2000). A third research project, Climator, was eventually developed in order to apply the results of this integrative modelling approach to the production of standardised guidelines for agriculture and forestry. Its results were translated into a Green Paper aiming to help forest and agriculture managers and policy–makers anticipate the adaption of the timber and paper production.

Overall, we found that researchers' commitments to 'micro–regimes' of anticipation are partly related to, and dependent on, the types of relations they have with forest managers. Their relations with forest managers should not be considered end–products of their research (as researchers disseminate scientific results to managers in the form of guidelines, advice or technical support) but also as determining the type of anticipatory research agenda and practices that researchers are developing (Granjou and Mauz, 2012). For instance, having close relations with research managers will provide resources (i.e. funding, project partnerships) for developing research agendas and activities aiming to predict the future conditions of forestry and to help forest managers (i.e. commitments to the first micro–regime). On the other hand, researchers committed to the second 'micro–regime' (anticipating future tree biology) and working in fundamental research institutions usually have less close relations with forest managers, who are not that interested in understanding the very basic ecological mechanisms of trees in a changing climate. Eventually, researchers committed to the third 'micro–regime' (monitoring forests as indicators of climate change) have developed close relations with policy–makers (especially from the Ministry of the Environment via the ONERC), and those relations help provide resources that fuel the agenda of monitoring forests as indicators of climate change. As a result, researchers' anticipatory agendas and practices tend to co–evolve with the nature and proximity of their relations with managers: their various relations to forest managers are an important part of the shaping, stabilization and evolution of their commitments to 'micro–regimes' of anticipation.

Conclusion

Overall, our results show that 'climatisation' (Aykut et al.., 2017) occurred in forest science and management not only at a discursive level—meaning the integration of the topic of climate change into forest science agendas and discourses—but also within organisations, collaborations and material infrastructures of knowledge, especially practices of data collecting and modelling (i.e. the network of forest observation sites called RENECOFOR, and the platform of models CAPSIS). The 'climatisation' of forest sciences also involves increasing exchanges and collaborations between forest science, ecology and climate science and the models that were previously developed in isolation in each of those fields. Yet, our fieldwork also points to the co–existence of a plurality of research agendas dedicated to anticipating the future of forests under a changing climate. These research agendas differ in two ways: they develop forest–driven vs. climate–driven science on one hand, forestry–oriented versus ecological and biological process–based research on the other hand. Our results do not only suggest how groups of environmental scientists, experts and decision makers hold various and potentially conflicting views regarding which research fields, predictive technologies and anticipatory governance are worth developing to produce sound science insights into environmental futures, they also highlight the embedment of the predictive models developed by forest scientists and experts within various and partly conflicting politics of environmental anticipation, including concerns for adapting forestry practices to future climates ('micro–regime' 1), for anticipating the ecological resilience of trees and forests ('micro–regime' 2) and for mapping and preparing the advent of climate change and its impacts ('micro–regime' 3). Forest researchers' commitments to the 'micro–regimes' and their various visions of what knowledge matters not only correspond to their professional trajectory and affiliation (i.e. belonging to fundamental or more management–oriented research institutions). They also tend to co–evolve with the nature and proximity of their relations with forest managers, as, for instance, having close relations with research managers will favour research agendas and activities aiming to predict the future conditions of forestry and help forest managers. On the other hand, researchers committed to the second regime have fewer close relationships with forest managers, while researchers committed to the third 'micro–regime' have rather developed relationships with national policy–makers in the field of forest, agriculture and environment.

Let us briefly return to the recent literature on the emergence of a 'regime of anticipation' that challenges previous models of predicting the future through the calculations of risk probability based on past data series (Amoore, 2013; see also Aradau and van Münster, 2013). Instead of the rise of a global, all–encompassing regime of anticipation accompanied by a new "conjectural episteme," our fieldwork in the case of French forest science and management suggests that the transformations of forest science and forestry practices aiming to anticipate climate change entail the co–existence of various, partly conflicting anticipatory 'micro–regimes' at work, whose goals and approaches to science, forest and the future are different. Our fieldwork suggests that Amoore's and Aradau and Van Münster's thesis does not do justice to current changes in the knowledge production practices which aim to capture environmental changes and futures. Instead of one unique way of constructing the future as an object of knowledge and action, we found several anticipatory assemblages that seek to foresee the future evolution of French forests in a changing climate, various visions of the extent to which the future is disruptive and a variety of practices and strategies for producing future–oriented knowledge. While in the first 'micro–regime', predictions rely on assembling past and present data into ever more sophisticated and integrative predictive projections, in the second regime, anticipating ecological changes requires scientists to modify the core of their models in order to predict how basic ecological mechanisms will evolve. In the third 'micro–regime', researchers aim to produce ever more accurate indicators of the on–going and future progress of climate change drawing on data collection.

Lastly, the embedment of a predictive research agenda setting within an environmental issue framework and political choices suggests that anticipatory pluralism is important in keeping a broad range of futures open to scientific and public scrutiny. In line with the new political sociology of science (Frickel et al., 2010), we argue that this plurality is essential in avoiding certain futures being completely unaddressed and unscrutinised (for instance, should the anticipation of forestry practices adaptation become hegemonic over the anticipation of tree species extinctions and 'natural' forest ecosystem destabilization). Documenting the variety of predictive scientific practices is instrumental in understanding the various and partly conflicting ways in which environmental futures are known, predicted and acted upon.

References

Adams HD, Williams AP, Xu C, Rauscher SA, Jiang X and McDowell NG (2013) Empirical and process–based approaches to climate–induced forest mortality models. *Frontiers in Plant Science* 4: 438.

Adams V, Murphy M and Clarke AE (2009) Anticipation: Technoscience, life, affect, temporality. *Subjectivity* 28(1): 246–265.

Aleixandre–Benavent R, Aleixandre–Tudó J, Castelló–Cogollos L and Aleixandre J (2017) Trends in scientific research on climate change in agriculture and forestry subject areas (2005–2014). *Journal of Cleaner Production* 147: 406–418.

Amoore L (2013) *The politics of possibility: risk and security beyond probability*. Durham, NC: Duke University Press.

Ancelin P, Courbaud B and Fourcaud D (2004) Development of an individual tree–based mechanical model to predict wind damage within forest stands. *Forest ecology and management* 203: 101–121.

Andersson J and Duhautois S (2016) Futures of Mankind: The Emergence of the Global Future. In: Van Münster R and Casper S (eds) *In the Politics of Globality: Assembling the Planet*. Oxford: Routledge, pp.106–125.

Aradau C and van Münster R (2011) *Politics of Catastrophe. Genealogies of the Unknown.* London: Routledge.

Aykut SC, Foyer J and Morena E (eds) (2017) *Globalising the Climate. COP21 and the 'climatisation' of global debate*s. London: Routledge.

Bloomfield BP (1986) *Modelling the world. The social constructions of systems.*London: Blackwell.

Callon M (eds) (1998) *The Laws of the Markets*. Oxford, UK: Oxford University Press.

Chuine I (2000) A unified model for tree phenology. *Journal of Theoretical Biology* 707: 337–347.

Chuine I and Cour P (1999) Climatic determinants of budburst seasonality in four temperate–zone tree species. *New Phytologist* 143: 339–349.

Coleman R and Tutton R (2017) Introduction to Special Issue of *Sociological Review* on 'Futures in Question: Theories, Methods, and Practices.' *The Sociological review* 65(3): 440–447.

Collins H and Pinch T (2002[1998]) *The Golem at large: What everyone should know about technology*. Cambridge: Cambridge University Press.

Cordonnier T, Courbaud B and Franc A (2006) The effect of colonization and competition processes on the relation between disturbance and diversity in plant communities. *Journal of Theoretical Biology* 243(1): 1–2.

Courbaud B, Pupin C, Letort A, Cabanettes A and Larrieu L (2017) Modelling the probability of microhabitat formation on trees using cross–sectional data. *Methods in Ecology and Evolution* 8(10): 1347–1349.

Dahan–Dalmedico A (2006) *Les Modèles du futur. Changement climatique et scenarios économiques: enjeux scientifiques et politiques.* Paris: La Découverte.

Dahan–Dalmedico A (2010) Putting the Earth System in a numerical box? The evolution from climate modeling toward global change *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* 41(3): 282–292.

Decocq G, Kalaora B and Vlassopoulou C (2016) *La forêt salvatrice. Reboisement, Société et Catastrophe au prisme de l'Histoire*. Ceyzérieu (Ain): Champ Vallon.

Dufour–Kowalski S, Courbaud B, Dreyfus P, Meredieu C and de Coligny F (2011) Capsis: an open software framework and community for forest growth modeling. *Annals of Forest Science* 69(2): 221–233.

Edwards PN (2010) *A Vast machine: Computer Models, Climate Data and the Politics of Global Warming.* Cambridge and London: MIT Press.

Estiarte M, Vicca S, Peñuelas J et al. (2016) Few multiyear precipitation–reduction experiments find a shift in the productivity–precipitation relationship. *Global Change Biology* 22: 2570–2581.

Farquhar GD, von Caemmerer S and Berry JA (1980) A biochemical model of photosynthetic CO2 assimilation in leaves of C3 species. *Planta* 149: 78–90.

Frickel S, Gibbon S, Howard J, Kempner J, Ottinger G and Hess D (2010) Undone science: charting social movement and civil society challenges to research agenda setting. *Science, Technology & Human values* 35(4): 444–473.

Gea–Izquierdo G, Guibal F, Joffre R, Ourcival JM, Simioni G and Guiot J (2015) Modelling the climatic drivers determining photosynthesis and carbon allocation in evergreen Mediterranean forests using multiproxy long time series. *Biogeosciences* 12: 3695–3712.

Granjou C and Mauz I (2012) Expert activities as part of research work. The example of biodiversity studies. *Science and Technological Studies* 25(2): 5–22.

Granjou C and Walker J (2016) Promises that matter. Reconfiguring ecology in the ecotrons. *Science and Technology Studies* 29(3): 49–67.

Granjou C, Walker J and Salazar J (2017) The politics of anticipation: On knowing and governing environmental futures. *Futures* 92: 5–11.

Gustafson E, De Bruijn A, Pangle R et al. (2015) Integrating ecophysiology and forest landscape models to improve projections of drought effects under climate change. *Global Change Biology* 21(2): 843–856.

Hacking I, (1994) Styles of Scientific Thinking or Reasoning: A New Analytical Tool for Historians and Philosophers of the Sciences. In: Gavroglu K, Christianidis J and Nicolaidis E (eds) *Trends in the Historiography of Science.* Dordrecht: Springer Netherlands, pp. 31–48.

Jasanoff S and Martello M (2004) *Earthly politics*. *Local and Global in Environmental Governance.* Cambridge and London: MIT Press.

Jabot F, Faure T and Dumoulin N (2013) EasyABC: performing efficient approximate Bayesian computation sampling schemes using R. *Methods in Ecology and Evolution* 4(7): 684–687.

Knorr–Cetina K (1999) *Epistemic Cultures. How the sciences make* knowledge Cambridge and London: Harvard University Press.

Korzukhin MD, Ter–Mikaelian MT and Wagner RG, (1996) Process versus empirical models: which approach for forest ecosystem management? *Canadian Journal of Forest Research* 26(5): 879–887.

Kwa C (2011) *Styles of knowing. A new history of science from ancient times to the present*. Pittsburgh: University of Pittsburgh Press.

Lagarrigues G (2016) Effects of environmental gradients on demographic processes and the durability of the uneven–aged forest management: application of Approximate Bayesian computation to improve simulation models. PhD Thesis, Université Grenoble Alpes, France.

Lafond V, Cordonnier T, Zhun M and Courbaud B (2017) Trade–offs and synergies between ecosystem services in uneven–aged mountain forests: evidences using Pareto fronts. *European Journal of Forest Research* 136(5/6): 997–1012.

Law J and Mol A (eds) (2002) *Complexities. Social Studies of Knowledge Practices*. Durham and London : Duke University Press.

Legay JM (1997) *L'expérience et le modèle. Un discours sur la méthode.* Paris : INRA Editions.

Lempereur M, Limousin JM, Guibal F et al. (2017) Recent climate hiatus revealed dual control by temperature and drought on the stem of Mediterranean Quercus ilex. *Global Change Biology* 23(1): 42–45.

Leslie PH (1948) Some further notes on the use of matrices in population mathematics. *Biometrika* 35(3/4): 213–245

Loustau D (2004) *Final report of the project CARBOFOR. Carbon sequestration in the big forest ecosystems in France. Quantification, spatialization, vulnerability and impacts of different climatic and forestry scenarios*. INRA/CNRS, France, June 2004.

Mackenzie D, Muniesa F and Siu L (2007) *Do Economist Make Markets? On the Performativity of Economics*. Princeton: Princeton University Press.

Michael M (2017) Enacting Big Futures, Little Futures: Toward an ecology of futures. *The Sociological Review* 65(3): 509–524.

Misson L, Rocheteau A, Rambal S, Ourcival JM, Limousin JM and Rodriguez R (2010) Functional changes in the control of carbon flux after 3 years of increased drought in a Mediterranean evergreen forest? *Global Change Biology* 16(9): 2461–2475.

Mol A (2002) *The Body Multiple: ontology in medical practice*. Durham and London: Duke University Press.

Morin X, Fahse L, Scherer–Lorenzen M and Bugmann H (2011) Tree species richness promotes productivity in temperate forests through strong complementarity between species. *Ecology Letters* 14(12): 1211–1219.

National Observatory on the Effects of Global Warming (2010) *Climate Change's indicators' list*. Report to the French Ministry of the Environment.

Perez–Ramos IM, Ourcival JM, Limousin JM and Rambal S (2010) Mast seeding under increasing drought: results from a long–term dataset and from a rainfall exclusion experiment. *Ecology* 91: 3057 – 3068.

Pestre D (2003) Regimes of knowledge production in society: Towards a more political and social reading *Minerva* 41(3): 245–261.

Renecofor's assessment committee (2006) *Renecofor network's evaluation. Suggestions for the future.* 14th November 2006

Roques A (2015) *Processionary Moths and Climate Change: An Update*. Springer Netherlands.

Rossi JP, Garcia J, Roques A and Rousselet J (2015) Trees outside forests in agricultural landscapes: spatial distribution and impact on habitat connectivity for forest organisms. *Landscape Ecology* 31(2): 243–254.

Sarewitz D, Pielke RA and Byerly R (2000) *Prediction: science, decision making and the future of nature.* Washington DC: Island Press.

Shinn T (1999) Change or mutation? Reflections on the foundations of contemporary science. *Social Science information* 38(1): 149–176.

Skrydstrup M (2017) Envisioning the future by predicting the past: Proxies, praxis and prognosis in paleoclimatology. *Futures* 92: 70–79.

Tavory I and Eliasoph N (2013) Coordinating Futures: Toward a Theory of Anticipation. *American Journal of Sociology* 118(4): 908–942.

Thuiller W (2003) BIOMOD – optimizing predictions of species distributions and projecting potential future shifts under global change. *Global Change Biology* 9(10): 1353–1362.

Vieilledent G, Courbaud B, Kunstler G, Dhôte JF and Clark J (2010) Individual variability in tree allometry determines light resource allocation in forest ecosystems: a hierarchical Bayesian approach. *Oecologia* 163(3): 759–773.

Notes

1 Another example is the creation of the A-FORCE network ("Adaptation des FORêts au Changement ClimatiquE" i.e. Adaptation of Forests to Climate Change) which comprises 15 research institutes, engineering schools and the ONF, with the aim of promoting and supporting climate change knowledge transfer from research laboratories to forest managers. In particular, A-FORCE seeks to avoid misunderstandings of modelling and simulation results and their uncertainties among forest managers.

2 The founder of SAMSARA, who works at IRSTEA, is in frequent contact with the National Forest Office in order to both collect data and to transmit SAMSARA results to forest managers with the goal of improving forestry strategies. SAMSARA is also used for training forest practitioners.

3 Today, large controlled chambers for the measurement of gas exchanges between plants and the environment exist in most major universities and agronomic institutes, for example New Zealand's Biotron, the Bioklima project in Norway, the ecotron projects in Germany and in Belgium. Many more ecotron-like facilities are in progress.