PhD position: Methodological advancement for adaptive decision support in forest management

End to candidate : 30 june 2024
Start of the PhD : 1st October 2024

Discipline : Applied mathematics, forest ecology, modeling, silviculture

Subject :

Background and objective:

Climate change increases the risks associated with ecosystems by increasing climate hazards and vulnerability. Indeed, ecosystems are becoming more fragile as a result of: (i) the gradual increase in temperature[1], (ii) the increased frequency of extreme events[2], and (iii) the increased vulnerability to biotic hazards[3]. The combined increase in hazards and ecosystem vulnerability can be linked to an increase in the vulnerability of human populations dependent on ecosystem services4 (ES). In this context of multiple risks, forest socio-ecosystems are a telling example of the interdependence between climate and biotic change, ecosystem disturbance and the provision of services to human societies. Indeed, forests provide ES that require collective management as common pool resources due to: (i) their universally recognised benefits to populations, (ii) the impossibility of excluding them from access to these benefits, and (iii) their vulnerability to depletion due to changing circumstances[5] or to inappropriate resource extraction.

Sustainable management of these systems requires a change in both forest planning and silvicultural practices. However, this new planning cannot be achieved without a research effort: (i) to identify the levers and bottlenecks, and (ii) to conceptualise the methods that will allow it to be implemented as efficiently as possible. The multi-species biotic structure of forest ecosystems, coupled with their non-linear, multiscale dynamics, make them complex systems that are even more complicated to manage, especially when management actions are intended to balance short- and long-term constraints and objectives. Forest ecosystems are also unique in that they bring together a large number of stakeholders with different (and sometimes conflicting) objectives in management decisions[6], which can lead to situations that are difficult to arbitrate. Without integrated and adapted tools to animate and guide this decision-making process, it can lead to costly impasses in the maintenance and resilience of forest ecosystem functioning and associated ecosystem services[6,7].

This thesis focuses on the problem of adaptive forest management by developing an operational methodological formalisation for the sustainable management of ES as commons in forest ES. We will propose an integrated and innovative tool, a mechanistic model-control-theory-adaptation pathway, which will be developed by a student (with feedback from stakeholders) and tested on a practical case, in collaboration with UMR SILVA's Forest'InnLab. This thesis can be divided into 4 main challenges.

Proposed breakdown and method :

Challenge 1: Analysis of forest ES through adaptive management

The first challenge is related to the need to model and predict the effects of management on different dimensions of forest system condition, services and stakeholders. In this work, we have chosen to work with the ForCEEPS[8,9] individual-centred gap model. This model will be further developed to take better account of forest management. This will make it possible to model forest management in all the richness of the choices it actually allows (renewal as well as thinning).

It will then be necessary to formulate the control problem(s) by considering the problem of spatial scale change associated with the difference between the scale of control application and that of constraint application (Figure 1-B). In addition, we will be working in a context where constraints may evolve over time. The information needed to define the objectives in terms of services to be provided, i.e. the constraints to be applied when defining the control problem, will be derived from the stakeholder consultations carried out as part of the Living Lab approach[10] (Figure 1-A).

Challenge 2: Defining adaptive action policies using viability theory

This challenge is related to selecting the sequence of management actions that will satisfy a set of ES supply constraints. Potentially, the targeted actions are part of a much larger set of possible actions of interest. A subset of management itineraries using expertise to define sylvicultural actions, as is more traditionally done, not carries risks and is less likely to generate innovative solutions to emerging related forest management problems.

Tools derived from decision sciences, and in particular from control theory, aim to systematise and accelerate this search by making it possible to find at least one sequence of actions that satisfies a set of constraints associated with numerous SEs. However, this analytical approach has mainly been tested on models of simple dynamic systems with a smaller number of variables[11] and not on mechanistic models. This second challenge therefore consists in developing/consolidating probabilistic approaches for mechanistic models that can approximate the exact solutions that would be proposed by viability theory (*Malara et al., in prep.*).

Challenge 3: Using the adaptive pathways framework to formalize management scenarios

SEF stakeholders need to find the best representation of the solutions that can emerge from modelling to ensure viable adaptive forest management. However, adaptation actions that are viable in the short term may become unviable in the longer term due to changes (e.g. environmental or economic). Conversely, long-term adaptation measures may conflict with short-term objectives. This requires all stakeholders to regularly adapt their objectives, constraints and operational organisation over time, as formalised by the Dynamic Adaptive Policy Pathway (DAPP[12,13]). Thanks DAPP, stakeholders will then define a series of decision nodes to plan possible transitions between adaptation options in anticipation of unforeseen changing circumstances.

DAPP has not yet been coupled with quantitative models, in particular forest mechanistic models, and even less with tools derived from viable control theory, as proposed in this thesis (Figure 1-C). A methodological formalism will therefore need to be developed, building on previous work (*Brias et al., in prep.*).

Challenge 4: Comparing the results of decision-support tool with feedback from stakeholders

This challenge consists in participating in the presentation of operational results to the stakeholders initially involved in the co-construction of desirable management scenarios (Figure 1-D), in collaboration with an engineer specialised in Living Lab facilitation.

The Living Lab[14] method, which includes the use of the decision support tool developed in this thesis, has never included the results of model projections as elements of reflection given to stakeholders, and even less so with the formalism proposed in this thesis. This approach would make it possible to identify a set of viable management scenarios without any preconceived ideas and to compare them with the range of scenarios proposed by stakeholders.

It is also important to assess how operational this mechanistic coupling of model, control theory and adaptation pathways is in practice. At the very least, this initial confrontation will allow us to highlight the strengths, weaknesses and areas for improvement of this formalisation and, if possible, to integrate certain necessary changes (Figure 1-E). This part of the work will be carried out with a research engineer specialised in Living Labs.

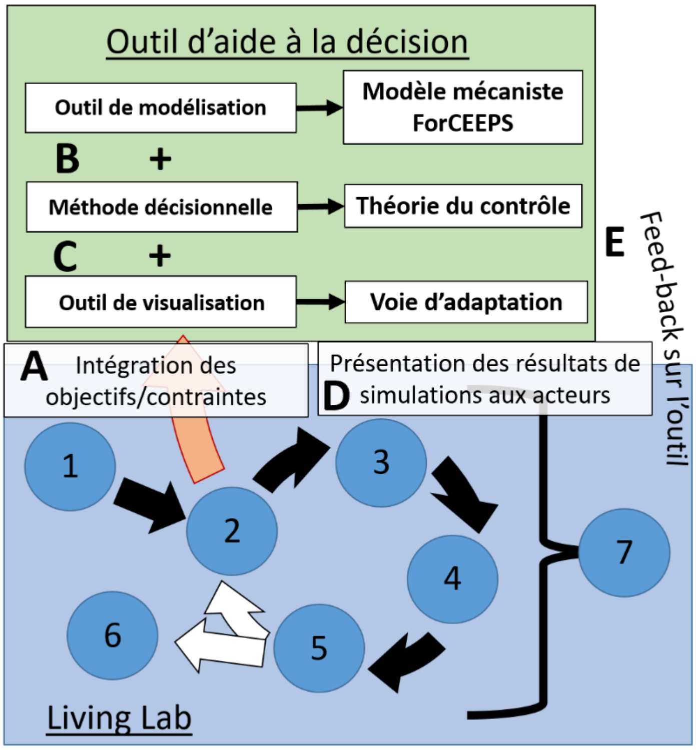

Figure 1: *Synthetic plan for coordinating the different challenges included in the thesis. The doctoral student's work will mainly focus on the decision support tool (green), the key steps (A-E) are detailed in the document. A specialized engineer will provide support for the Living Lab part (blue). The numbers represent the different stages of the Living Lab: 1-Planning, 2-Exploration, 3-Co-construction, 4-Experimentation, 5-Evaluation, 6-Deployment and 7-Process evaluation.*

Management and work environment

Director: Meriem Fournier (DR APT, UMR SILVA)
Co-directors:
- Marion Jourdan (CR INRAE, UMR SILVA)
- Jean-Denis Matthias (DR INRAE, UR LISC)
- Jean-Baptiste Pichancourt (CR INRAE, UR LISC)

Associated laboratories :

The thesis will be based in Nancy at UMR SILVA, under the supervision of Meriem Fournier and Marion Jourdan. UMR SILVA brings together researchers from AgroParisTech, INRAE and the University of Lorraine to conduct multidisciplinary research on wood, trees and forest ecosystems. The main scientific objective of UMR SILVA is to develop applied research to answer questions from society, including forest managers, on (1) the role and future of forest ecosystems in the context of global change, including climate change, and (2) the future of the wood industry (https://silva.nancy.hub.inrae.fr/).

The PhD student will benefit from a pleasant and stimulating working environment in terms of forestry research, in a dynamic team focusing on both ecological and social science issues, and encouraging interdisciplinary work. The PhD student will have the option of teleworking.

Regular exchanges and several trips will be made to Clermont-Ferrand, to optimize collaboration with Jean-Denis Mathias and Jean-Baptiste Pichancourt of the UR LISC. The research themes of INRAE's UR LISC focus on the study of complex systems. The laboratory is particularly interested in controlled dynamic systems and viability theory (https://lisc.inrae.fr/).

Expected skills :

Profile required:

Master 2 in applied mathematics with a strong interest in ecology, Master 2 in ecology with a strong interest in mathematics or agricultural engineer. Profiles from courses combining social sciences, environmental sciences and/or modeling will also be considered.

Additional technical skills: Proficiency in at least one programming language (Python, R, java, C++), fluency in English (oral and written).

Desired skills : Autonomy, ability to work in a team and with operational players, curiosity, rigor, interest in interdisciplinarity and multi-laboratory/site collaborations.

Driving license

Bibliographie :

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