CLAND CHALLENGE 2- FOOD, WATER AND BIONERGY SECURITY UNDER CLIMATE CHANGE

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Disclaimer - this text has been written to implement the Challenge 2 as described in the proposal. After receiving expressions of interest from all CLAND teams, it is subject to adjustments.

All the young scientists hired in all the CLAND projects will be in a host team / lab for day-to-day supervision. Co-supervision by at least two teams in different laboratories organized by responsible for each research line. Co-supervision includes participation to regular progress meetings with the young scientists hired, official joint PhD supervision in the case of PhD students, discussing new ideas, joint writing of publications and visits in the co-supervising lab(s). At this stage, possible co-supervision were identified but we will wait for expressions of interests from all CLAND research teams to set the co-supervising scheme in each RL.

Research Line 2.1 Effect of recent climate change (trends and extremes) on crop and livestock production

Overview

The main objective of this research line is to analyse the productive performance of agricultural systems, both in terms of the average trends and of inter-annual variability (fluctuation around time trends), and to quantity the effects of extreme climatic events on agricultural productions at large scales (regions, countries, continents, world). The work will be organised into three work packages.

In WP1, experimental data and surveys will be used to estimate the time trends of production levels for a large diversity of agricultural systems (intensive, organic, agro-ecological etc.). Year-to-year variability will be analysed from production anomalies (differences between yearly productions and fitted trends), and the results will be used to check whether recent climate change led to an increase or to a decrease of production instability in major producing areas. We will identify the relationships between the trends of average yields and trends of yield variability.

In WP2, production anomalies computed in WP1 will be related to weather-based indices using global climate reanalysis datasets. A large range of indices will be then ranked according to their ability to anticipate past yield losses (hind-cast analysis). Results will be used to select the most predictive weather indices for major crops, and explore their practical values, especially for weather insurance systems.

Finally, in WP3, we will explore contrasted land use scenarios at large scales (defined in collaboration with other RL of CLAND) and evaluate the trade-off between high level of average production and low production inter-annual variability. Results obtained in WP1, WP2 and WP3 will be used to find optimal land use allocations adapted to climate changes, able to offer a good comprise between high average production and low instability.

WP 2.1.1 Assessing average production levels and inter-annual variability of contrasted agricultural systems

The objective is to evaluate a range of contrasted agricultural systems according to two categories of production criteria, namely the average productive performance (ex: average crop yields, yield trends) and inter-annual variability (ex: yield variance, yield coefficient of variation, expected shortfall). These two categories of criteria will be evaluated using two sources of information:

- Experimental data collected worldwide for various types of agricultural systems and analysed using meta-analysis techniques (provided by other projects, see below) (Cernay et al. 2016; Hossard et al., 2016; Lesur et al., in press),
- Time series derived from official statistics on agricultural productions in major producing areas (Cernay et al., 2015; Michel and Makowski, 2013).

These two sources of information will be used to estimate time trends and indices measuring production variability (Cernay et al., 2015; Lesur et al., in press). The first source of information (experimental data, see below) will be used to compare different types of cropping systems in different continents (Hossard et al., 2016), while the second source (yield data derived from official statistics) will be used to compare several major crops (e.g., maize, soybean, rice, wheat) and to check whether recent climate change led to an increase/decrease of production instability in major producing areas. Various classifications of cropping systems will be considered, but we will give a strong focus on the comparison of conventional *vs*. organic systems, and on the comparison of simplified systems vs. diversified systems, as several authors hypothesized that some of these systems were more resilient than others.

The evolution across time of yield trend and of yield inter-annual variability will be analysed for the considered crops and cropping systems. Results will be used to rank a large range of crop species and of cropping systems according to their levels of production instability. The evolution of this ranking across time will be analysed in details.

CLAND research units involved: UMR Agronomie, UMR SAD-APT, LSCE.

Main collaborators:

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Relation with other projects:

- EU project DiversImpact (one post-doc funded by this project during one year),
- AgroBio4 project Alecapab.

These two projects will give us access to experimental data collected in several continents. The project Alecapab will give us access to several long-term experiments comparing organic vs. conventional systems (a dataset was built at UMR Agronomy in March-June 2017 on this topic). One of the tasks of the EU project DiverImpact is to gather available experimental results on the relative performance of diversified cropping systems (e.g., intercropping, rotation including a high number of crops, agroforestry). We will be able to benefit from the work done in this project in 2018. We will also use some of the experimental yield data of the global legume database of Cernay et al. (2016).

WP 2.1.2 Selection of weather-based indices to anticipate yield loss before harvest

In this WP, we will consider a large range of weather-based indices (from simple average temperature to crop model outputs) and evaluate their ability to anticipate yield losses before harvest (from a few month to a few days before harvest). Evaluation of indices will be conducted from published global datasets including crop yields and weather time series, at various spatiotemporal resolutions.

We will elaborate from previous studies recently conducted at UMR Agronomie and at the AgroClim INRA unit (Ben-Ari et al., 2016; Sharif et al., 2017), and develop a generic procedure to evaluate weather-based indices from global yield and weather datasets. This procedure will be used to assess the proportions of yield losses correctly classified by the considered weather indices, and the proportion of wrong classifications, i.e., anticipated yield loss in the absence of actual yield loss (false positive), absence of anticipated yield loss in case of actual yield loss (false negative). We will map these proportions in function of the geographical locations of the crops, and check whether the misclassification rates evolved over time. This procedure will be applied in several geographical areas (especially, in Europe, America, China, and Africa) to rank weather indices according to their predictive performances.

The results of the weather index assessment described above will be used to explore the practical interest of weather index. In particular, we will assess the capabilities of a range of selected weather indices to anticipate yield loss before harvest under current and future climate conditions. We will also assess the ability of weather index crop insurances to mitigate adverse consequences of yield loss for farmers. The principle of weather index crop insurance is to pay an indemnity to farmers as a function of some weather index; a pre-selected weather index (*I*) is used as a proxy for yield loss, and a payout is triggered when the value of *I* is lower that an index threshold, *i.e*. the strike (*S*). The choice of *S* is critical because its value influences the performance of the insurance system. The use of an inappropriate strike level may thus lead to a payout in the absence of actual yield loss, or to an absence of payout in case of actual yield loss. We will use weather indices showing low misclassification rates to develop prototypes of insurance systems in producing areas characterized by substantial levels of yield instability. We will then compute the probabilities of true positive (payout in case of actual yield loss) and of true negative (no payout in case of absence of actual yield loss) associated with these insurance systems. The computed true positive and negative probabilities will be used to determine optimal values of *S* across space and time, and assess the potential benefit of weather-index insurance.

Main collaborators:

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- Joint Research Center (Ispra, Italy)
- T. Klein (insurance company, Switzerland)
- AgroClim INRA unit
- + Post-doc funded by CLAND.
- + PhD student funded by CLAND

WP 2.1.3. Optimizing portfolio of land use activities to reduce production instability at large scales

In WP3, we will explore contrasted land use scenarios at large scales, and evaluate the trade-off between high average production and low inter-annual variability across these scenarios. A land use scenario is defined here by the proportions of land allocated to a given agricultural activity (ex: production of soybean) in different geographical areas (ex: different départements in France, or different countries in Europe). A land use scenario is seen here as a land portfolio (defined by the geographical land allocation) whose performances are summarized by the average total production (ex: average soybean production in Europe over all countries) and by the level of inter-annual variability of the production (ex: inter-annual variance of soybean production in Europe) (Ben-Ari and Makowski, 2016).

Results obtained in WP1 will be used to design several land use scenarios showing contrasted productive performances, in terms of both average production and of instability. In particular, we will consider scenarios with large shares of legume crops and of organic systems in Europe, and scenarios with large share of feed production in Africa. When relevant, we will evaluate the capabilities of these scenarios to feed animals, for example poultry in Africa. Other RLs of CLAND will be involved in the design of these scenarios.

Results obtained in WP2 will be used to evaluate how these scenarios could perform under climate changes. Niche modelling and optimisation procedures (e.g., quadratic programming) will be used to define optimal land use allocation adapted to climate changes, i.e., offering a good compromise between high average production level and low inter-annual instability. Possible shift of production areas will be considered, especially in Europe for soybean. Finally, results obtained in WP2 will be used to study the consequences of a deployment of index insurances on the level of risk associated with contrasted land use scenarios.

Main collaborators:

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- CIRED

Research line 2.2 – Optimizing food production systems under climate and environmental pressure

Second draft – Muriel Tichit (INRA) and Julien Tournebize (IRSTEA) 2017/07/27

Overview

Growing human population puts rising demands on agricultural productivity to secure food, fibre, and bioenergy (Foley et al. 2005; Tilman et al. 2011). This increasing demand for yields also increases pressure on the environment with chemical inputs and natural habitat modifications that degrade biodiversity and ecosystem services. These trade-offs between food production, biodiversity and ecosystem services are further complicated through a rapidly changing climate (Lobell & Burke 2010) which will severely impact European agriculture both biophysically (Zabbel et al. 2016) and economically (Van Passel et al. 2016).

Ecological intensification (Doré et al. 2011; Bommarco et al. 2013) has been proposed as an attempt to substitute chemical inputs through 'effective' ecosystem service management to minimize yield gap. One of the underlying intuition is that 'effective' management of agricultural land can preserve ecosystem services and facilitate climate change adaptation (Tscharntke et al. 2012). However, we know little about how 'effective' management does look like and how 'effective' management can soften trade-offs between agricultural production and ecosystem services under climate change.

Land sharing / sparing has been proposed as a land management strategy for reconciling food production and biodiversity conservation (Green et al. 2005). Several studies in tropics demonstrate the benefit of land sparing (e.g. Phalan et al. 2011). Sparing is not always the best strategy in temperate farmland where recent studies conclude that mixed strategies (combining sparing and sharing) can soften trade-offs (Teillard et al. 2016; Dross et al. 2017). Recent analysis reports that land sparing[1] can potentially offset greenhouse gas emissions from agriculture in the UK (Lamb et al. 2016). However, this study ignores the consequences of yield intensification on biodiversity, ecosystem services, water quality in farmland along with potential displacements effects (Grau et al. 2013).

There is a current lack of understanding (and synthesis, and regional / global upscaling) on how land management strategies might affect the provision of food, multiple ecosystem services while minimizing environmental impacts and how current trade-offs might be modified by climate change. The goal of RL2.2 is to explore the potential of ecological intensification and sparing / sharing in a changing climate. The work will be organized into three workpackages.

WP2.2.1 develops climate sensitive ecological production functions (EPF) to predict agricultural production (crop and animal source food), ecosystem services, biodiversity and impacts on large gradients of agricultural systems (for France and EU27). We use EPF to determine biophysical trade-offs and rank management actions and areas.

WP2.2.2 articulates EPF into models that can reveal the relationship among services, and identify management options that soften trade-offs. We use these models to study through optimization and viable control theory the potential of climate change to modify tradeoffs or synergies.

WP2.2.3 inventories new land uses aimed at softening tradeoffs. The method will be designed with decision makers (i) what-if scenarios and (ii) target-seeking scenarios to be assessed with the models developed in WP2. It provides a better understanding of decision makers' priorities for managing food, ecosystem services and biodiversity.

[1] Land sparing = increased agricultural yields, reduced farmland area and restored natural habitats on the land spared thus sequestering carbon.

WP2.2.1 – Multiple Ecological production functions

Objective and methods

The objective is to produce a set of ecological production functions (EPF) for predicting food production[2], ecosystem services[3] and environmental impacts[4]. EPF are regression models that measure the statistical influence of ecosystem characteristics (land cover, land use, land suitability, climate, soil) on ecosystem indicators for a given place and time via marginal changes (Wong et al. 2015; Jonsson et al. 2014). The consequences of climate and land use changes have not yet being taken into account in EPF.

To derive EPF that explicitly account for the combined effects of climate and land use change, we will adapt the framework by Princé et al. (2015). First, existing scenarios (e.g. IPCC-SSP and the older SRES scenarios) and expert-based scenario will be combined to derive projections of future climate, land cover, and land use. Second, projections will be integrated as predictors in EPF to forecast changes in ecosystem services. EPF calibration will be based on genetic algorithm (Accatino in rev).

Two sets of EPF will be developed: one for France and one for Europe. For France, we capitalize on the data set on ecosystem service developed in EFESE-EA. For water related EPF we rely on improved data set from IRSTEA. For Europe we use the MAES data set. EPF for agricultural production will quantify separately crop and animal source food as the two components do not rely on the same characteristics in terms of land cover/use, input use. Results from RL2.1 (WP1-2) are used to account for inter-annual variability of crop yield; integrating crop yield inter-annual variability into the crop-livestock balance (EFESE-EA, 2017) will generate an inter-annual variability of animal-source food. For biodiversity, we rely on French and EU data sets (Morelli et al. 2017).

This new set of EPF will enable to link hotspots and coldspots for each ecosystem service with their drivers. We will explore the spatial pattern of food and ecosystem services / biodiversity (France / Europe), finding out whether areas providing high levels of food co-occur in space with ecosystem service hotspots and coldspots. We will also compare congruence/mismatch between high nature value farmland and “unprotected” farmland in different EU regions. Ranking regions on the basis of congruence/mismatch will enable to identify regions where reconciling food production and ecosystem services is achievable with a land sharing strategy and regions requiring a land sparing strategy.

CLAND research units involved: UMR SAD-APT, IRSTEA, LSCE, UMR ECOSYS, UMR Agronomie, UMR ESE.

Main collaborators:

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- P. Martin (AgroParisTech, UMR SAD-APT)
- J. Tournebize and colleagues for working on improved EPF for water flows and quality (IRSTEA)
- P. Ciais, … (LSCE)
- B. Gabrielle (AgroParisTech, UMR ECOSYS)
- D. Makowski, … (INRA, UMR Agronomie)
- F. Chiron (Paris-sud, UMR ESE)
- One scientist from EFESE consortium and or EFESE CST (to be decided)

[2] crop and animal source food
[3] carbon storage, carbon sequestration, pollutant retention, annual water flow, pollination, erosion control, recreation
[4] water quality (nitrates, pesticides), biodiversity

- Expression intéret Stéphane Dupas DEEIT à l'IRD

Relation with other projects:

- EFESE-EA[5] (French National Ecosystem Assessment for agroecosystem)
- MAES (Mapping and Assessment of Ecosystems and their Services) developed by JRC
- FP7 TRUSTEE "Toward rural synergies and trade-offs between economic development and ecosystem services".

EFESE-EA provides a dataset for 5 indicators of ecosystem services (pollination, erosion control, N water quality regulation, climate regulation, recreation) in French agroecosystems at the resolution of small agricultural regions. It will be used to improve EPF for the French case study. MAES provides a EU27 wall-to-wall data base (1km²) for 7 ecosystem services (carbon storage, carbon sequestration, pollutant retention, annual water flow, pollination, erosion control, recreation). It will be used for both French and EU analysis. FP7 TRUSTEE provides a French and EU data set for biodiversity (10km² and 50km²).

WP2.2.2 – Models for trade-off / synergy analysis between food production, ecosystem services, biodiversity and environmental impacts

The objective is to predict allocations of agricultural land use and land use intensity that maximize ecosystem service and biodiversity while maintaining food production and minimizing environmental impacts (water quality) at the scale of France and Europe. Two modelling approaches will be implemented: one based on optimization (for the French case study and for EU) and another based on viable control theory (for the French case study only).

The optimization model will consist in a set of interrelated EPF developed in WP1. Each EPF, predicting the different performance criteria (food production, ecosystem service, biodiversity and water impacts), is expressed as function of climate, soil quality, land cover, land use, management intensity (e.g. pesticide). The decision variables represent land management options (land and crop cover, land use, pesticide inputs) at 10km² and 50 km² cell for France and Europe respectively. The model will be calibrated for the diversity of production systems (starting with five production systems[6]: industrial crops, cereals, dairy cattle, beef cattle, mixed crop–cattle, and monogastrics). A multi-objective optimization will be performed with Non-dominated Sorting Genetic Algorithm-II (cf Teillard et al. 2016 for food/biodiversity trade-off).

The viable control model will be developed for the French case study. We will build on the state-and-transition model (Lohani et al. 2016 ; Lavorel et al. 2015). Viability theory will be used to perform a dynamical trade-off analysis. This mathematical framework makes it possible to define a set of limits beyond which there is no possibility to prevent the system from losing a desired property. It offers a powerful methodological option for target-seeking scenarios (cf WP 3). It is particularly adapted to account for adaptive management and extreme events (Accatino et al. 2014).

With the models developed in this WP, we will explore the efficiency of different land management options through simulation. We will quantify the potential of agroecological intensification, i.e. to what extend and where agricultural productivity can be enhanced while ensuring a no-loss on ecosystem services and biodiversity and maintaining environmental impacts below acceptable

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[5] The report was submitted to MEDDE on March 31st ; embargo until October 2017 ; data set should be available through the information system of INRA US-ODR in Toulouse in 2018.
[6] together, they account for 67 % of French farms, 80 % of French agricultural land.

thresholds. Models outputs will quantify and communicate expected consequences on complex tradeoffs. Visualization tools will be developed to support decision making.

CLAND research units involved: UMR SAD-APT, IRSTEA, UMR ECOPUB

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- V. Martinet (INRA, UMR ECOPUB)
- G. Deffuant (MOTIVE LISC, IRSTEA)
- A. Tonda, N. Boukhelifa (INRA UMR GMPA)
- …

Relation with other projects:

- Horizon 2020 – ANIMAL-FUTURE 'Steering Animal Production Systems towards Sustainable Future'

For the viable control model => on-going collaborations with G. Deffuant group at LISC and with Vincent Martinet. LISC develops tools and methods in applied mathematics to predict and manage the behaviour of complex systems. For optimization problems and complex trade-off we build on on-going collaborations with A. Tonda and N. Boukhelifa who develop tools for interactive Pareto frontiers exploration. For the EU level analysis, synergies will be organized with Animal-Future on multi-level trade-off analysis and visualization.

WP2.2.3 – Land management option space for adapting food production systems to climate change

The objective is to combine ecological intensification and sparing/ sharing frameworks to explore options for adaptation. Two approaches will be developed: what-if scenarios and target-seeking scenarios (IPBES, 2016). What-if scenarios will examine a range of plausible futures, based on changes in land management strategies (for instance different mix of ecological intensification and sparing / sharing). Target-seeking scenarios will represent agreed-upon future targets (food, ecosystem services, biodiversity, water quality). The empirical material for scenario building will combine both knowledge from literature[7] and from decision makers. We will capitalize on recent meta-analysis to inventory new land management options aimed at softening trade-offs (Benton et al. 2016). Participatory methodology will support the design of the two types of scenarios together with decision makers.

The option space will be explored quantitatively using models from WP2. Option space will consist in a broad suite of ecologically based management implemented with sparing/sharing strategies. Capitalizing on Dross (2016) we will develop sparing / sharing strategies specific to crop and livestock land uses. For instance, a sparing strategy could consist in an increase in the total area under permanent grassland and wetlands. A crop sharing strategy could consist in a (massive) decrease of management intensity in croplands (reduced pesticides inputs). Livestock sharing strategy could consist in decreasing intensity of land dedicated to cultivated fodder. Etc..

[7] For instance published forecasts for 2050 on cropland output intensification and cropland expansion, and efficiency measures in the livestock system (increases in feed-conversion ratios) and demand-side measures (quantitative and qualitative changes in the human diet).

CLAND research units involved: UMR SAD-APT, IRSTEA, UMR ECOPUB, UMR ESE

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- V. Martinet (INRA, EcoPub)
- J. Lecomte (Paris-sud, UMR ESE)
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Relation with other projects:

- Basc Flagship API-SMAL 'Agroecology and policy instruments for sustainable multifunctional agricultural landscapes'.
- Horizon 2020 – ANIMAL-FUTURE 'Steering Animal Production Systems towards Sustainable Future'.
- Horizon 2020 – SURE-FARM 'Towards sustainable and resislient EU farming systems'.

Api-Smal will provide a framework which extends sparing / sharing framework to the provision of multiple ecosystem services across scales. We will also capitalize on the agroecological solution inventory built in Api-Smal. **Animal-Future** and **Sure-Farm** will provide European inventory of farm innovation for resilient crop and animal production. This inventory will complement the literature review on land management options aimed at softening trade-offs.

Research Line 2.3 – Optimizing forest management under climate pressure

Overview

Climate change is already impacting the structure and functioning of forests globally, and projections indicate that climate change will become one of the most important factors driving changes in forests in the future (Settele et al., 2014). Climate change can have positive or negative effects on forest productivity and other ecosystem services (e.g. carbon storage) that strongly depend on the interactions between climate and other drivers, especially rising atmospheric CO_2 concentrations, nitrogen deposition and forest management (Ciais et al., 2005; Jonard et al., 2015; Piao et al., 2017). These changes are occurring in the context of increasing pressure for production of wood, fibre and bioenergy, as well as large regional differences in the rates of deforestation (primarily in the tropics), afforestation (primarily in temperate regions), and reforestation (FAO 2015).

This Research Line focuses on developing and testing process-based models of forest ecosystem functioning (in particular Ecophysiological-Forestry Models, EFMs, e.g., Bellassen et al., 2011; Guillemot et al., 2014) that can take into account climate change, rising atmospheric CO_2 concentrations, nitrogen deposition, and key management strategies, and then applying these models to explore the options for forest management that could reinforce the capacity to adapt to climate change while also sustaining capacity for bioenergy and wood production. EFMs are particularly good model candidates for the purpose of this Research Line. Being process-based, they are more likely to be robust under future environmental combinations (Elith et al. 2010) than empirical models. Since RL2.3 considers managed forests, with typical simple structures and low tree species diversity, the limitations of EFMs (i.e. consideration of even-aging and monospecificity) will largely be overridden by their demonstrated ability to simulate accurately the carbon sink capacity of forests (e.g. Delpierre et al., 2012; Kuppel et al., 2012; Guillemot et al., 2017). Work in this Research Line will focus on, but will not be limited to, temperate and Mediterranean forests, where management generally plays a much larger role than in tropical and boreal forests.

A variety of management strategies have been proposed to reinforce the adaptive capacity of forests at stand and regional levels. These strategies include: (1) increasing the resistance and resilience through management of ecosystem functioning, for example by reducing stand density to reduce the risk of drought stress (Guillemot et al. 2014), or by minimizing soil disturbance during harvesting, (2) selecting heat and drought tolerant tree species during stand regeneration, (3) increasing species and genotype diversity at within- or between-stand levels and (4) planting introduced heat and drought tolerant tree species or genotypes (Legay & Mortar 2006, Lindner et al. 2010, Lefèvre et al. 2014). Noticeably, there has been little consideration of the interacting role of nutrients (nitrogen, N, and phosphorus, P) in the adaptive capacity of forests. This point is pivotal in a context of increasing wood and fibre demand where the intensification and higher frequency of thinning implies higher nutrient exports (Mérino et al. 2005).

The work in Research Line 2.3 will focus on management strategies that can be tested using existing EFMs for homogeneous stands (e.g., Guillemot et al. 2014, decreasing LAI to reduce drought vulnerability), because management strategies based on increasing stand heterogeneity (e.g., bolstering within-stand genetic variability) are currently difficult to test rigorously with well-validated models.

The overall goal of Research Line 2.3 is to provide a numerical assessment of these strategies, for serving as inputs to assist the reflection of foresters' national offices and policymakers in shaping the future of managed forests. It will take the form of numerical experiments performed with EFMs under current and future environmental (climate, atmospheric composition and deposition) conditions. The considered EFMs will first be calibrated (WP1 and WP2) against existing data for strengthening the robustness of the numerical experiments (WP3).

In WP1 we will parameterize EFMs under current climate and nutrient (N, P) deposition conditions, with the aim to represent the interacting influences of pedo-climatic conditions and management on the C and nutrient productivity of well-documented European stands, for the most common European tree species (e.g. deciduous oaks, European beech, Norway spruce, Scots pine).

In WP2 we will further detail the parameterization of EFMs with two aims: (i) representing alien species of increasing use in European forestry practices (e.g. *Pseudotsuga menziesii, Eucalyptus sp.*) and (ii) evaluating, beyond species-specific parameterization, the influence of regional vs. local parameterizations (assumed to summarize local adaptation) or, when relevant, clone-specific parameterizations, in simulating the carbon productivity of managed forests.

In WP3 we will evaluate the productivity and sustainability (i.e. resistance and resilience to climate extremes) of forests under combined CO_2, climate, N deposition and management scenarios.

The CASTANEA (developed by ESE/IDEEV) and ORCHIDEE (developed by LSCE) EFMs are at the centre of Research Line 2.3. CASTANEA (Dufrêne et al. 2005) is an ecophysiological model designed for simulating the water and carbon budgets of even-aged, mono-specific forest stands. It is parameterized for the main species currently used in European forestry (European beech, European deciduous oaks, Norway spruce, Scots pine, Silver fir, Holm oak). CASTANEA has proved able to simulate accurately both the exchanges of CO_2 between forests and the atmosphere and the aboveground woody growth of forests over their current measured timescales (i.e. from hours to one decade as concerns CO_2 fluxes, Delpierre et al. 2012, and from years to decades as concerns woody growth, Guillemot et al. 2017). CASTANEA has further proved to accurately simulate the Beech and temperate oaks distribution at both the French (Cheaib et al., 2012) and European scales (BNP Paribas FATES project, Pasturel et al., in prep.), based on GPP and aboveground growth outputs. Recent developments include (i) the coupling with the FAGACEES forestry module (Guillemot et al. 2014) allowing both the simulation of forest management on stands stocks and fluxes and the apportionment of stand-scale growth among tree diameter classes, (ii) the representation of the direct impacts of temperature and water stress on tissue (wood and leaves) growth (i.e. sink-limitation) on top of the C source-limitation of growth (Körner, 2015; Guillemot et al., 2017), (iii) the implementation of the N cycle, with explicit representations of the diffusion and mass flow of ions in the soil to the root surface and the limitation of growth by N reserves (Delpierre et al., unpublished). The model development benefits from the high quality data and inputs provided by forestry partners (RENECOFOR-ONF, NFI-IGN) through different research projects.

ORCHIDEE (Krinner et al 2005) is a Dynamic Global Vegetation Model which is the land-surface model of the IPSL-CM6 earth system model. ORCHIDEE has further been designed to study the global biogeochemical cycles and conduct impact studies at scales from the country to the globe. For this purpose, new features are progressively included in ORCHIDEE to be able to represent different processes. Two major developments are undergoing: (1) the simulation of the coupled C/N/P cycles and (2) the simulation of the main agrosystems: forest, crops and grassland including management. The forestry module has been first developed based on the coupling of ORCHIDEE with FAGACEES model (Bellassen et al. 2010a, b). It has been improved in a new version named ORCHIDEE-CAN aiming at representing both the biophysical and biogeochemical impacts of forest management on climate (Naudts et al. 2016). The other important development is, first, a representation of the nitrogen cycle (Zaehle et al. 2010) and now also the phosphorus, which frequently imposes limitation on vegetation growth (Goll et al. In prep). The coupling of ORCHIDEE-CAN with the coupled C/N/P is under development.

The CASTANEA and ORCHIDEE models offer a complementary approach. On one hand, CASTANEA is designed to address questions at scales raging from the forest stand to the region (e.g. country, continent). It has been extensively validated and parameterized for the forest species used in France and Europe. To this respect, it is expected to best address questions about forest management relevant for "local" policies. On the other hand, ORCHIDEE is more generic and as such expected to better address large-scale policies (e.g. at the European scale). Moreover, as it represents different agrosystems, ORCHIDEE can address the questions of forestry management linked to the others agrosystems. We envision both models to act complementarily along the continuum from the local to the continental scale. In order to evaluate thoroughly both model abilities in providing options for forest management that could reinforce the capacity to adapt to climate change, it is necessary to conduct a common evaluation of models skills and a quantification of differences at a given operational scale. This will be done by sharing both input (forcings) and model validation data, and possibly model parameterization methods. Beyond identifying the relative strengths of both models across scales after proper calibration (WP1 and WP2), we will use both models as for evaluating the uncertainty of the projections scenarios for forest adaptation (WP3).

WP2.3.1. Parameterizing Ecophysiological-Forestry Models

The design of Ecophysiological-Forestry Models (EFMs; Bellassen et al., 2011; Guillemot et al., 2014) has (1) extended the spectrum of data against which forest ecosystem functioning models are testable (i.e. inventory data instead of integrated stand-scale productivity) and (2) broadened the scope of ecophysiological models' predictive capacity. These models are now able to simulate the influence of different management intensities / scenarios on forest productivity and ecosystem function.

EFMs have proved their ability to simulate ecosystem CO_2 fluxes (e.g. Delpierre et al., 2012; Kuppel et al., 2012) and tree biomass increment data (Guillemot et al., 2017) over relatively short time scales (decades) as compared to a typical forest rotation. This has demonstrated their ability to simulate key characteristics of forest ecosystem function, but these models still lack a proper evaluation against forestry data that provide the opportunity to test models over longer time scales (either by exploiting long time series data, or through space-for-time substitution) and under different management regimes (e.g. silvicultural intensity).

In addition, validation of most EFMs has been done under the hypothesis of constant N and P availabilities. In order to be operative at simulating the interacting influences of management with climate change, CO_2 increase and N deposition, EFMs need a critical assessment and parameterization of the N and P cycles modules. Testing of the forestry management modules is also a high priority.

Objectives of WP1:

- Parameterize the Ecophysiological modules of EFMs including N and P cycles data. This objective will be achieved against (1) national survey monitoring networks (ICP-Forests at the European scale, and RENECOFOR at the national scale for France) which measure both components of the N and P cycles (e.g. biomass, nutrient content per unit mass, concentrations in soil solution etc.) and stand productivity (e.g. through forest inventories and in some cases dendrochronological data), as well as (2) ICOS (former CarboEurope) data, at sites which measured components of both the C and N cycles. The parameterization will be conducted for the main tree species used in European forests (i.e. European beech, deciduous oaks, Norway spruce).

- Parameterize the Forestry modules of EFMs using forestry field trials, aiming at quantifying the influence of stand management (focusing on stand density) on productivity. This objective will be achieved against GIS-COOP data. It consists in diameter and height data conducted every third year in stands of highly contrasted management intensities, from free individual growth to self-thinning conditions. Those data are currently available, in pure stands, for deciduous oaks, Douglas fir and Maritime pine.

Partners involved: ESE (CASTANEA model), LSCE (ORCHIDEE model), ICP-Forests (of which RENECOFOR), INRA (several flux towers), ICOS-ecosystems, member teams of GIS COOP

WP2.3.2 Identifying species and provenances functional effects with Ecophysiological-Forestry Models

EFMs have typically been parameterized at relatively large taxonomic scales (i.e. PFT or species; Peaucelle et al., 2016) that do not account for the functional influence of genetic diversity among populations of a functional type or a species (Kramer et al., 2008). In this respect, EFMs are currently not designed for considering the adaptive potential of local provenances, which are both (1) valued by foresters for adapting productivity to local pedo-climate conditions and (2) considered as a tool (through human-assisted migration or the selection of particular provenances) for increasing the resistance of forests to the detrimental effects of climate change (Bontemps & Bouriaud, 2013).

In EFMs, plant entities (be they PFTs, species or provenances) are represented by a particular set of parameters and / or equations. Their parameterization at the PFT or species scale does not allow quantifying the potential of local provenances in adapting forest productivity to global changes. More, there is a need for a proper quantification of the influence of species (as opposed to provenances) on the simulated local productivity. This highlights the need for developing proper parameterizations for introduced species (e.g. *Pseudotsuga menziesii, Euclayptus* sp.) which are of increasing use in Europe, and for which EFMs still need parameterizations and testing.

The aim of WP2 is to conduct an analysis of the local (i.e., provenance scale) vs. regional (i.e., species scale) parameterization of EFMs. The "local" parameterizations of EFMs will be conducted in homogeneous ecological regions (e.g. Sylvo-Eco Regions SERs in French NFI) for an ensemble of species. The plausibility of the local parameterization will be compared (1) with regional-scale common garden data for the few species (e.g. Beech and Scots pine) and traits (e.g. phenological traits) for which such data are available (e.g. von Wuelisch, 1995; Kramer et al. 2017; such data are accessible for France in the PLANTACOMP network, coordinated by INRA) and (2) with climate-trait relationships (Peaucelle, 2016). "Local" parameters may be interpreted as "provenances" and afterwards be used for performing "human-assisted transplant" modelling experiments (see WP3). Parameterizations derived at the "regional" level in WP2 will rely on the upper-taxonomic scale parameterization derived in WP1.

Partners involved: ESE (CASTANEA model + legal and technical aspects of provenance transplants), LSCE (ORCHIDEE model + climate-trait relationships), IGN (French NFI), INRA PLANTACOMP (Christel Anger GBFOR INRA Orléans)

WP2.3.3. Projection of species/provenances, management and global change interactions

The aim of WP3 is to provide a numerical assessment of the strategies considered for reinforcing the adaptive capacity of forests subject to climate, atmospheric composition and deposition changes, in a context of increasing wood demand. Among those strategies, WP3 will focus on the interactive effects of forest management, species and provenance identities on the productivity and sustainability (i.e. resistance and resilience to climate extremes and environmental trends) of French forests under combined CO_2, climate, N deposition and management scenarios.

One objective of WP3 is to produce maps of optimized species/provenance*management interactions for different combinations of CO_2 and N deposition trajectories. Building on the EFMs parametrizations derived in WP1 and WP2 at the species and provenance scale, we aim at identifying at horizon 2050 and 2100 which combinations of species/provenance and management intensity maximise on the long run (1) the wood productivity and (2) the carbon storage of forests, while reducing the risk of drought-induced stand mortality.

A second objective of WP3 is to assess the impact of actual management strategies on the future state of the French forests carbon sink. After mapping with the ONF the actual management scenarios over France, and their foreseeable future, EFMs will be used to simulate the trajectory of the forests productivity and carbon stores under different RCP and N deposition scenarios.

The objective of WP3 is to provide a numerical assessment of the impacts of the manoeuvrable aspects of forest management (i.e. species/provenance and management intensity) in interaction with anthropogenic global changes. For this assessment to be fully informative, it must provide as an output the uncertainty of the predicted variables of interest (i.e. productivity and carbon stock). Among the sources of uncertainty, different climate, CO_2 and N deposition scenarios will be forced as inputs to the EFMs. Beyond that, we will work at estimating the uncertainty in predictions related to the model parameterization through the propagation of plausible parameter ranges and correlations as determined through Bayesian calibration frameworks (Kuppel et al. 2012; Guillemot et al. 2017) in WP1 and WP2. To this respect, the use of two EFMs will provide an estimate of the uncertainty related to the model structure itself.

Collaborations: ESE (CASTANEA model), LSCE (ORCHIDEE model), ONF (definition of management scenarios).

Proposed allocation of CLAND resources

Challenge 2			Host unit	Secondment unit	Lab & entity receiving the funds for the recruitment	TIMELINE 2018 Jan. June	2018 July Dec.	2019 Jan. June	2019 July Dec.	2020 Jan. June	2020 July Dec.	2021 Jan. June	2021 July Dec.
RL 2.1	WP 2.1.1	Post-doc	Agronomie	LSCE									
	WP 2.1.2	Post-doc	Agronomie	LSCE									
	WP 2.1.3	PhD											
RL 1.2	WP 2.2.1	Post-doc	SADAPT LSCE ECOSYS Agronomie IRSTEA ?										
	WP 2.2.2	PhD		IRSTEA									
	WP 2.2.3	Post-doc	SADAPT LSCE ECOSYS Agronomie IRSTEA ?										
RL 2.3	WP 2.3.1	PhD	ESE (PhD1)	ES5 (PhD2)	Univ Paris-Sud LSCE (PhD2)								
	WP 2.3.2	PhD	LSCE (PhD2)	CIRAD Montpellier + LSCE (PhD1)	Univ Paris-Sud LSCE (PhD2)								
	WP 2.3.3	PhD + students ?											

Summary and explanation for the funding requested from CLAND in RL2.1

- Postdoc 1 on WP2.1.2 to be hired in 2018 at Agronomie in secondment with LSCE. for the EU level analysis (autumn 2017)
- One PhD thesis on WP2.1.3 to be started in 2019- PhD to be recruited for the French level analysis (autumn 2018)

Summary and explanation for the funding requested from CLAND in RL2.2

- One three year post-doc in charge of EU level analysis (WP1-WP2-WP3) to be hired in autumn 2017 who will work transversally with SADAPT LSCE ECOSYS Agronomie IRSTEA.
- One PhD thesis for French case study optimizing food production ecosystem services, biodiversity and water quality to be started in 2018, in collaboration with IRSTEA (co-funding with Metaprogramme ECOSERV to be planned…).

Summary and explanation for the funding requested from CLAND in RL2.3

- 2.3.1 : **Expected CLAND funding:** 2 PhDs starting on S2-2018 (half grants) + 1 MSc (starting S1-18)
- 2.3.2 : **Expected CLAND funding:** 2 PhD starting on S2-2019 + 1 MSc (starting S1-19)
- 2.3.3 : **Expected CLAND funding:** 2 PhD ½ grants starting on S2-2021

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