The mountain environment, a driver for adaptation to climate change

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Abstract

The mountain environment is perceived today by vine-growers as a strong structural constraint. Yet in the current context of climate change, in which we turn to genetics, irrigation or innovation in cultural practices to maintain production quality, could the mountain environment emerge as a solution for adapting to climate change in vine-growing? Here we explore the role of cooperative policies that may be deployed on the territorial scale, using an agent-based model. Our model was based on the viticulture of the Banyuls-Collioures AOC area, which is characterized by small-scale vine-growers and marked by widespread involvement in cooperative systems. The simulation results showed an important role of cooperative policies not only to conserve narrow production window and required vine quality, but also in respect of the emblematic landscape structure. These results should foster vine-growers to strengthen their cooperatives and adequately use these organizations to mitigate future climate change impacts.

Keywords : Agent based modeling, viticulture, landscape, climate change

1 Introduction

Agro-systems are kinds of ecosystems maintained under human control to ensure productions. The human-environment interaction confers to these systems important complexities (Smajgl and Barreteau 2013) that generate non-linearity when environmental changes happen. In the context of ongoing climate change, it is important to evaluate what kind of adaptation humans should make to keep

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the production going on these agro-systems (Field et al. 2014) bearing in mind their specific complexities.

Wine-growing areas are examples of such agro-systems and their production is highly dependent on environmental constraints. Climate change is a major stress added to those that already weigh on viticulture (Nemani et al. 2001; Jones et al. 2005; White et al. 2006). Controversies about the future of viticulture appear (Hannah et al. (2013) VS Van Leeuwen et al. (2013)). Hannah et al. (2013) illustrate on the possibility that areas will become unsuitable to vine-growing. However, Van Leeuwen et al. (2013) argue that local complexity confers possibilities for adaptation. If climate change is not disputed, it is the vine-grower capacity to take advantage of their environment and agricultural practices that now need to be explored. A corpus of scientific studies emerged in the literature to tackle these issues with methodologies as diverse as genetics and vine phenology (Duchêne et al. 2012), social aspects (Viguié et al. 2014), agricultural practices (Herrero-Langreo et al. 2013) or spatial-explicit climatology (Moriondo et al. 2013; Quénol et al. 2014; Briche et al. 2014; Cuccia et al. 2014).

Agent-based modeling is a methodology that allows exploring and understanding the complex interactions between societies and their territories. Originally, these modeling tools were reserved in the fields of research in artificial intelligence. In the past 20 years, they have been widely adopted in empirical disciplines (also in social sciences) to explore computationally how individual behavior influences systems of interests (Janssen and Ostrom 2006; Smajgl and Barreteau 2013). Agent-based modeling also allows to establish cross-disciplinary contexts around a model to go deeper on the understanding of the complexity under analysis (Bousquet and Le Page 2004; Gilbert and Troitzsch 2005).

By introducing space in agent-based models, a new level of complexity can be reached where interactions between agents and with their spatially-explicit environment are described (Evans et al. 2006). These models can be used to introduce constraints in a controlled world (Berger, 2001 ; Veldkamp and Lambin, 2001 ; Veldkamp and Verburg, 2004), and assess the impacts of different variables on the system under consideration (Irwin and Geoghegan, 2001). This type of virtual experiments were defined as "lab experiments" (Janssen and Ostrom 2006; Robinson et al. 2007).

Mountainous territories (territory defined here as a physical space and a social space) are particularly good examples of complex systems (Haslett 1997) that present local adaptation possibilities. The mountain environment is often perceived by farmers, and perhaps more so by vine-growers, as a natural handicap which must be lived with. The Banyuls-Collioure AOC (Appellation d'Origine Contrôlée or Controlled Designation of Origin) in the Pyrénées-Orientales area of France can be seen as one of those places where human has been able to form emblematic landscapes (Briffaud and Davasse 2012). These landscapes form a heritage-rich territory used as a marketing vector (François et al. 2006), but are gradually being neglected. High and sloping areas are slowly being abandoned. The fact that the system is set in a cooperative context also brings its share of stimulation and constraints for the territory (Touzard, Draperi, et al. 2003). This area is representative of the southern part of France where most of the wine production is made by small-scale vine-growers who are mainly organized in cooperatives (CCVF 2013). Meanwhile, questions of adaptation to climate change are becoming increasingly pressing (Van Leeuwen et al. 2013), particularly in the south of France and Mediterranean Basin. Irrigation and genetics are being put forward as ways of mitigating alterations caused by climate change to the product (Acevedo-Opazo et al. 2010). Nevertheless, the structural handicap of mountainous areas could be transformed into an asset for the future by using altitude to preserve a balance in crop maturity. What would be the future of these areas if tomorrow the mountain environment was no longer perceived as a constraint, but rather as a land of refuge to face climate change?

We will explore this question via a spatially-explicit agent-based model, by focusing on the self-organization strategies implemented by agents to meet the cooperative's quality requirements. We have created a simulation environment, built from geographic information system data, field surveys and economic values related to the Banyuls-Collioure AOC area. This work has two aims considering climate change: 1- to provide global insight into how a mountainous vine-growing area can react and adapt to new challenges, and 2- to investigate cooperative policies and their implication on the vineyard landscape stability that can be a source of local development.

2 Materials and Methods

2.1 Study area

The Banyuls-Collioure AOC is located between the sea and the mountains over 4 different districts (Figure 1). The altitude ranges from sea level to 988 m with a gradient varying from 0 to 180%. Its climate can be identified as Mediterranean (Carbonneau et al. 2007). In 2012, vineyards covered 1300 ha over the 7748 ha of the 4 districts (i.e. just under 17% of land cover). Vineyards represented 90% of agricultural activity on the AOC territory and involved 680 vine-growers in 2012. The Banyuls-Collioure AOC allows 2 types of wine production: Banyuls wine which is a fortified wine ("vin doux naturel"), unlike the Collioure wine which is a dry wine. Both are made with the same vines, and differ by the grapes blend and maturation in the winery.

According to the Defense and Management Organization (ODG)1, representing AOP vine-growers of Banyuls viticulture, the cooperative system and small-scale viticulture have strong dominance on the social structure (94% of vine-growers are members of one of the three cooperatives, this covers 79% of the vineyards). For illustration, the average surface area per vine-grower in 2012 was 1.9 ha while the minimum installation surface area was 2.5 ha (defined by the French ministry of agriculture). This system of garden-scale vine-growing has been questioned into question over the past few years, as vineyards are no longer being passed on and production costs are too high because of steep slopes (the mean slope on vine plots is 44%).

In the Banyuls-Collioure AOC area the cooperatives are facing variations in quality related to the total acidity of harvest and the alcoholic potential. With climate change, the temperature rise is expected to increase acidity since the total acidity is correlated with temperature (see the works of ; Buttrose et al. (1971) ; Leeuwen et al. (2004) (Sweetman et al. 2014) ; and the cases we measured in the Banyuls-Collioure AOC in Appendix A). In low elevation plots the

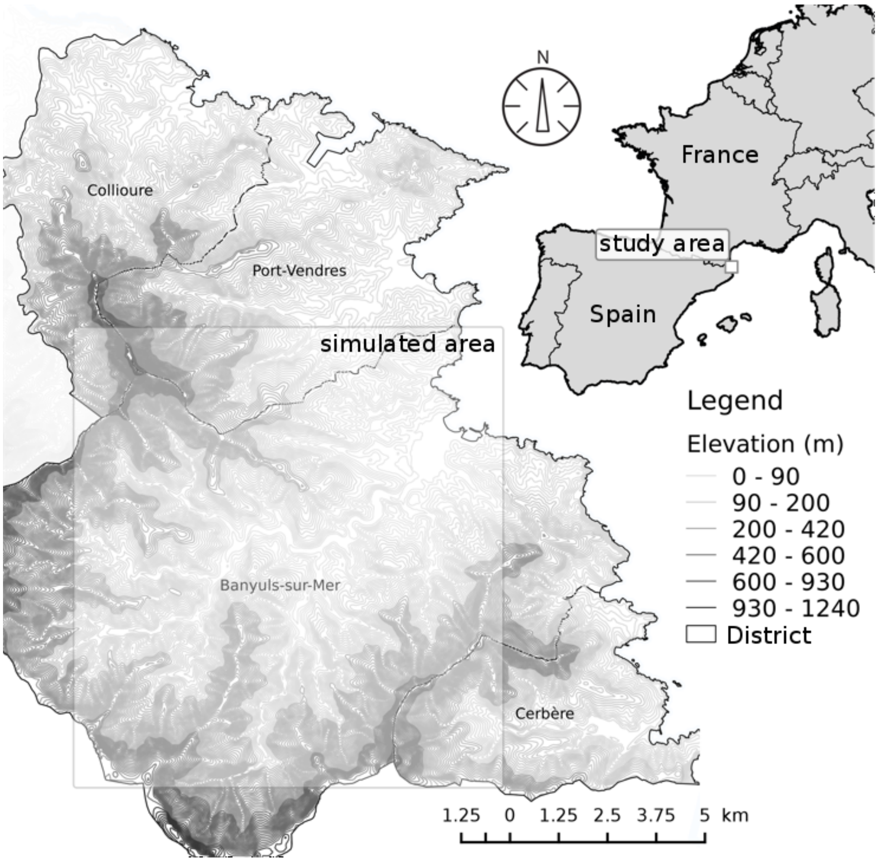

Figure 1: Map showing the Banyuls-Colioures AOC area. The isolines colors describe elevation (light gray=low and black=high elevation), the dashed lines delimit the 4 districts and the square is the zone integrated and used in the model.x

alcoholic potential is high while total-acidity is too low. High elevation plots have opposite conditions: low alcoholic potential and high total-acidity. The current choice is to wait for a suitable total acidity, but it faces high alcoholic proportion. The risk is to obtain wine above 15% vol and loose the AOC certification. Concerning the winery management, spatial disparities of these two variables involve a large time window for harvesting. Increasing the time window for harvest implies high production costs. Indeed, these small cooperatives need to hire temporary employee to receive the harvests. This complicates the winery management and raises questions about economic and spatial cooperative policies.

2.2 Developing the model

The agent-based model presented here was developed on the basis of interviews with vine-growers and local technicians (as "expert knowledge", Smajgl, Brown, et al. (2011)) and the model was developed as a "lab experiment" (Janssen and Ostrom 2006; Robinson et al. 2007; Smajgl, Brown, et al. 2011). The calibration was discussed with official stakeholders (agricultural technicians, cooperative technicians). We used the Netlogo platform (Wilensky 1999) to implement the model. The formalization of the model description complies with the ODD (Overview, Design concept, Details) description protocol (Grimm, Berger, Bastiansen, et al. 2006; Grimm, Berger, DeAngelis, et al. 2010).

2.2.1 Objectives

This model aims to explore the response of a territory (Brunet and Théry 1993) to various vine-grower remuneration policies by the cooperative in the context of climate change.

2.2.2 Entities, state variables and study scale

Temporal scale: Each iteration of the model represents one year. Simulations are set to last 100 years although we focused in particular on the first 50 years of the model. The 100 years horizon was kept to test the model's stability and sensitivity to parameter variations (see Appendix B).

Spatial scale: The model focus on a 39 km2 section located on the Banyuls-Collioures AOC (Pyrénées-Orientales, France) covering a large part of the Baillaury catchment basin in the district of Banyuls (Figure 1). The Netlogo model has a resolution of 80x68 patches (a patch is considered arbitrarily as a plot of 1ha) to perfectly cover the projection of our study area.

Model organization: The deciding agents in the model are the vine-growers. The agent can choose to cultivate or abandon plots according to his environmental perception capacities. These decisions are influenced by an additional overarching agent: the cooperative. The cooperative can have from a "non-interventionist" behavior to an "interventionist" behavior by promoting specific acidities (see sub model (SM) 3). The patches, spatial units of the area, represent the cultivated plots and are also considered with their own specificities.

State variables: Each plot is characterized by: its temperature, acidity, current cover (unoccupied, urbanized, planted with vines or left fallow (i.e. with unused vines)), altitude, slope, its interest for vine-growers (regarding its position and its slope, see SM6), its owner, the plot's earnings and its production costs. Each vine-growers has the following attributes: his past and present economic capital, his plots collection (knowing which were in use or not) and his labor task force. He is able to calculate some indicators for the decision-making process such as the mean acidity of his plots (see SM4).

2.2.3 Processes and scheduling

Each simulation year starts and ends on the 15th of August. This date corresponds to the temperatures and acidity values reported on the 11 control plots (see Appendix A and Initialization section). Our model is subdivided into 7 sub models (c.f. details in sub models section). These sub models are illustrated in figure 2 and are organized as follows for each time steps:

- for plots (numbers 1, 2 and 3 in fig. 2):
  - temperature and acidity update. Temperature is considered as rising of 0.02^o per year (per iteration) and consequently acidity is decreased (cf. SM1).
  - bonus-malus update according to climate change. These bonus-malus are calculated by the cooperative for each plot, according to the local acidity and the remuneration strategy defined by the cooperative (cf. SM2).
- for vine-growers (numbers 3 to 7 in fig. 2):
  - update of the required labor for the year. If the vine-growers extend the land they cultivate, they have to update the cost of the required labor (cf. SM3).
  - update of the mean acidity of the plots (cf. SM4).
  - capital update. Each vine-grower receives the profits of his harvest (cf. SM5).
  - abandonment of plots (cf. SM6).
  - purchase of a plot according to available capital. The choice of this plot is based on the acidity values and on the available plots (cf. SM7).

2.2.4 Design concepts

Basic principle: Particular attention was paid to the spatial competition for the most attractive land between vine-growers (cf. SM7), and the varying abandonment rate according to the amount of bonus awarded by the cooperative.

Objective: Each vine-grower attempt to make his business sustainable and to optimize his responses to the system according to the changes in his environment. The cooperative pursues an objective which may prove contradictory with the vine-growers' practices by attempting to maintain a stable total acidity in the harvest received.

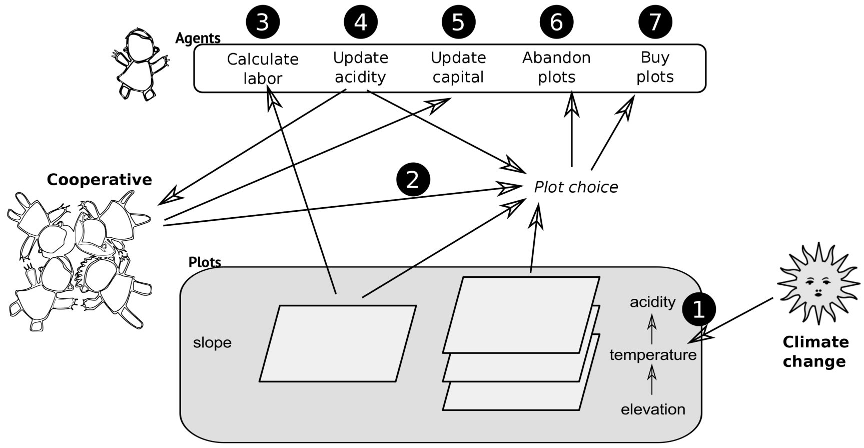

Figure 2: Overview of the model structure. Black circles give the order of process scheduling in simulations. The plot choice is a central event happening in the “Abandon plots” and “Buy plots” agents processes.

Emergence: According to the policy chosen by the cooperative we may observe an abandonment of high areas or, on the contrary, a race to the top of the mountains.

Observation: The model outputs are analyzed for each simulation focusing on the first 50 years of the simulation. At this time horizon, we observed the average number of plots cultivated, as well as the proportion of fallow plots as indicators of individual strategies driven by the cooperative's compensatory measures. We also looked at the mean acidity values of the vineyard plots as an indicator of success of the policy implemented by the cooperative. Finally we have used a landscape fragmentation index to highlight the vineyard landscape clustering. This index (IF) was computed as follow: $IF = Nfragment/Ntheo$ where Nfragment was the number of fragments in the landscape defined as a series of contiguous cultivated plots and Ntheo was the mean number of fragments in the landscape that could be observed under a hypothesis of complete spatial randomness for the same number of cultivated plots. This index gives an idea about the persistence of the inherited emblematic landscape. With values close to 1, the IF indicates that the landscape is as fragmented as under spatial randomness, meaning that the emblematic landscape disappeared. With values of $IF << 1$, the IF indicates a landscape with compact blocks of vineyards, which is the actual situation.

2.2.5 Initialization

The model is initialized based on the data obtained from a geographic information system (GIS) for the environmental variables. The altitude, slope, mean annual temperature and total acidity are the spatially distributed values. The spatially extrapolated temperatures of initialization are calculated by linear regression on elevation based on the data obtained from the 11 temperature sensors installed as part of the TERVICLIM/TERADCLIM/ADVICLIM[1] programs. The extrapolated acidities follow a linear relationship with temperature (Appendix A). Economic data of the study area were obtained from “expert opinions” of the Agricultural Development Group (GDA) for the Banyuls and Albères vineyards (who provided technical support for vine-growers) and from the Defense and Management Organization (ODG)[2], representing AOP vine-growers. The vine-growers are set with an initial capital (6000€) that enable them to generate their first harvests. Vineyard plots are set to produce 5900€per year (per ha) and the price to buy a plot that had never been cultivated is set to 33000€. We chose in this modelling study not to position the exact vineyard coverage and position for each vine-grower, but rather the general vineyard coverage for the catchment basin being simulated. During the initialization of each simulation, the GIS data described above as well as current vineyards position and urbanized areas are loaded into the patches as local variables. The town of Banyuls is positioned on the map and an initial population of 50 vine-growers is randomly positioned on the current vineyards. Each vine-grower is attributed 10 plots within a radius of 5 plots around his location. The scenarios, temperature change and analyses properly begin as soon as the vine-growers occupy the current vineyard coverage (loaded from GIS data).

2.2.6 External inputs

There is no external input to the system once the simulation begins.

2.2.7 Sub models

SM1 - Temperature and acidity update: The temperature rises in a linear manner with each iteration. In our analyses, the system is explored with an annual 0.02 degree Celsius increase. This corresponds to an increase of 2^oC in 100 years, which can be considered as "optimistic", relative to the numerous 21st century climate simulations experiences in the fifth phase of the Coupled Model Intercomparison Project (CMIP5) as reported by the IPCC (Field et al. 2014). What is important here is more the process of acidity increase than the value of temperature increase itself. Therefore, the harvest acidity (in $g \times L^{-1}$ of sulfuric acid) evolves in a linear manner in the model, but negatively in relation to the temperature following:

$$acidity_t = acidity_{t-1} - evt \times 0.7 \quad (1)$$

where evt is the temperature increase (0.02^oC), which is multiplied by 0.7 to take into account the correlation between acidity and temperature (Appendix A ; Buttrose et al. (1971) ; Sweetman et al. (2014)).

SM2 - Update of the amount of compensation by the cooperative: the general cooperative behavior can take two forms: 1) open strategy, when the cooperative imposes a target acidity s (set to 3 $g \times L^{-1}$ of sulfuric acid) that become a low limit for reward; or 2) closed strategy, when the cooperative has a more complex behavior where a low (s) and a high (s2) limits are imposed to the vine-growers. In the open strategy behavior, the bonus-malus for a plot

[1]http://terviclim.in2p3.fr/ consulted on 20th November 2014
[2]http://www.vins-cotevermeille.fr/contact consulted on 20th November 2014

(ac) is determined by the following formulas:
If the plot acidity is >= s:

$$ac = (acidity - s)e^{\mu} \times \frac{bonus}{s - max(acidity)e^{\mu}} \quad (2)$$

else

$$ac = (acidity - s)e^{\mu} \times \frac{bonus}{s - min(acidity)e^{\mu}} \quad (3)$$

where acidity is the plot's effective acidity (in $g \times L^{-1}$ of sulfuric acid), μ is the cooperative's behavior coefficient, bonus is the maximum bonus-malus penalty established by cooperative policies (in €), min(Acidity) and max(Acidity) are the theoretical minimum and maximum acidities (-4 and 12 $g \times L^{-1}$ of sulfuric acid respectively) expected in August 15 by extrapolation of acidity-temperature and temperature-elevation relationships. In the closed strategy, the behavior is similar to the open one when the plot acidity is < s (hence using equation 3) but if plot acidity is greater than s then the equation 2 is changed to :
if plot acidity < (s+s2)/2

$$ac = (acidity - s)e^{\mu} \times \frac{bonus}{\frac{s2-s}{2}e^{\mu}} \quad (4)$$

else
if plot acidity > s2

$$ac = (acidity - s2)e^{\mu} \times \frac{bonus}{\frac{s2-s}{2}e^{\mu}} \quad (5)$$

else

$$ac = (acidity - s2)e^{\mu} \times \frac{bonus}{(s2 - min(acidity))e^{\mu}} \quad (6)$$

The variation of μ alters the type of answer that the cooperative choose to give concerning the quality of harvest to be met. Figure 3 shows how with a simple variation of μ the behavior of the cooperative could be radically altered for both strategy (open or closed). All values of μ are theoretically usable, which means that all types of behaviors in relation to the possible acidity could be explored. Nevertheless, in the present study we chose to test only the values of 0, 0.5, 1 and 1.5.

SM3 - update of the required labor for the year: The vine-grower can have acquired a new plot the previous year. In this case, the required labor needs to be updated to represent the costs of the number of people needed to cultivate a plot. Labor is defined as follows in the model:

$$Mo = \frac{np}{Ct} = \frac{np \times slope}{100} \quad (7)$$

where np is the vine-grower's number of plots, slope is the mean slope of all the plots belonging to the vine-grower (in %o), Ct is the working capacity expressed in surface units and Mo is the required labor to maintain the vineyards (in man of work per year). This is used to assess the surface area that one person is able to cultivate per year according to the average slope of the vineyards area. Figure 4 shows the result of the calculation of Ct under different mean slopes. When the mean slope is less than 10% we set Ct to 10ha, which is a reasonable maximum

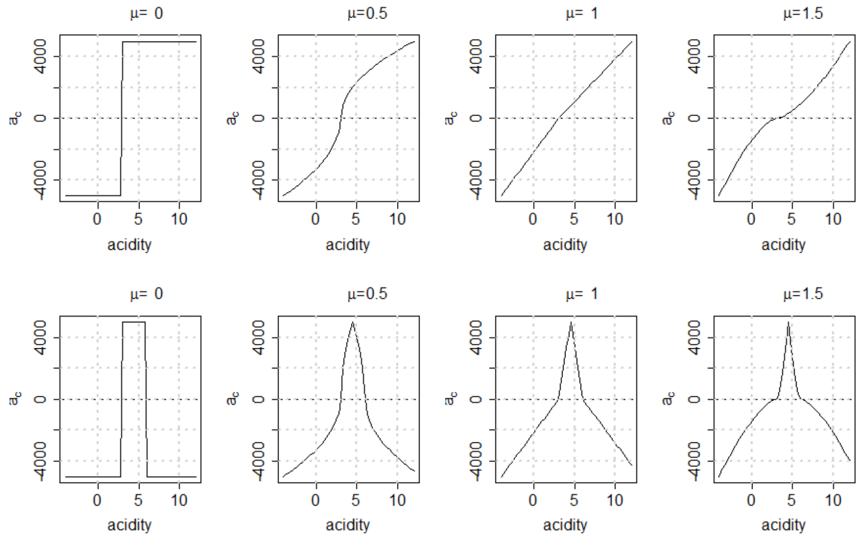

Figure 3: Example of 8 remuneration strategies by the cooperative according to acidity with a maximum bonus/malus parameter of 5000€. The first line is relevant for the open strategy of the cooperative and the second line for the closed strategy.

area that one person can cultivate. With this mathematical formulation, we assumed that with a mean slope of 20%, one person is able to cultivate 5 ha, whereas with a mean slope of 45%, one person can only cultivate 2 ha.

SM4 - Update of the mean acidity of the plots: At each iteration, the vine-grower assess the mean acidity of all the plots he is cultivating. This value helps him to make his purchasing choices (cf. SM7).

SM5 - Update capital: The vine-growers' capital is updated every year by using the costs and incomes of each vineyard plot. Annual production costs for each plot (apc) are calculated one time at initialization and take into account the plot slope and distance from the cooperative:

$$apc = (slope \times \beta) + (distance \times \epsilon) \quad (8)$$

where β is a fixed coefficient to increase production costs with increasing slope (set to 4 after trials and errors following pattern-oriented modelling ; Grimm et al. 2005), and ϵ is a fixed coefficient to increase production costs with distance to Banyuls city (identically set to 2). The 2500€value in equation 8 corresponds to a basic flat cost of maintaining a plot cultivated with vineyard.

Annual production income for each plot (api) depends on the acidity of the plot and cooperative behavior (ac, see SM2):

$$api = 5900 + a_c \quad (9)$$

The 5900€value corresponds to the selling of grapes from a plot to the cooperative. The vine-grower updates their capital with the following calculation:

$$capital = capital_{t-1} + sum_{j=1}^{n} api_j - sum_{j=1}^{n} apc_j - (Mo - 20000) \quad (10)$$

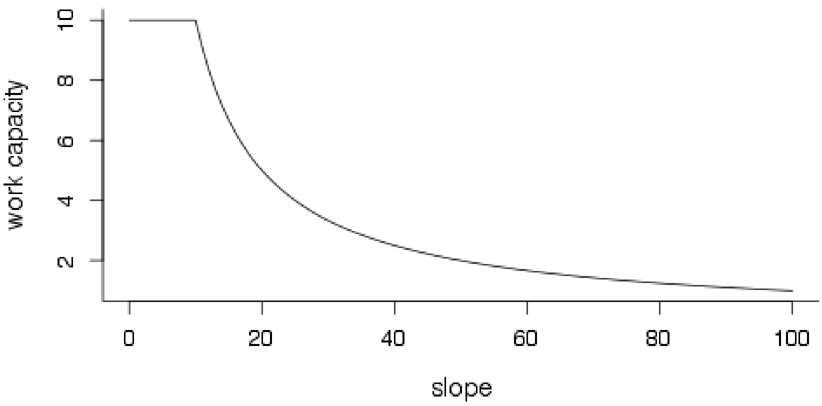

Figure 4: Working capacity of one worker per ha according to the mean slope of his plots in %

where j notes all the different plots belonging to a vine-grower, Mo is the required labor (SM3) and 20000€corresponds to the yearly salary of a vineyard worker.

SM6 - Leaving plots fallow : Leaving plots fallow is the only solution for a vine-grower to avoid paying the production costs for some of his plots. There are two possibilities in order for a vine-grower to implement this practice:

- he has plots which were no longer of "interest". This happens when he has unproductive plots (plots whose annual production costs without considering labor costs were higher than their annual incomes). He could then decide to leave one of them fallow.
- he has financial difficulties (i.e. his capital was decreasing). In this case, labor costs are too high for the actual collection of plots, so the vine-grower could choose to stop cultivating the least profitable plots (i.e. the one that has the highest production cost and lowest gain).

SM7 - Purchase of a plot: The vine-grower decides to purchase a new plot when his capital is higher than the basic annual production costs (2500€) and he is able to cover the additional production costs of a new plot for the coming 5 years. Plots could only be purchased within a radius of 2 plots around the plots already cultivated by the vine-grower. When these two first conditions are met, then the key condition for the choice of a new plot is the analysis of the mean acidity of the vine-grower's plots (SM4). If the mean acidity of his plots is greater than s (threshold determined by the winery's strategy, set to 3 $g \times L^{-1}$ of sulfuric acid) , the vine-grower would not take into consideration the acidity of the new plot when purchasing. If the mean acidity of the plots is lower than s, he would then seek to purchase a plot with an acidity greater than s. Finally, preference is given to the plot with the lowest production costs (SM5).

2.3 Simulations

A sensitivity analysis of the vine-growing system was conducted by 1- using an open or closed strategy of the cooperative (SM2), 2- modifying the maximum bonus/penalty from 0 to 5000 by increments of 1000 (bonus variable, SM2), as well as 3- modifying the μ value (the cooperative's behavior coefficient, SM2) from 0 to 1.5, by increments of 0.5. For each set of parameters (48 modalities), 40 simulations were performed with a maximum of 300 iterations or 100 years simulated (bearing in mind that the simulation of interest begins when the vineyard reaches its current coverage, see initialization). The observation variables described above (observation section) were collected and analyzed at the time horizon of 50 years. All the data obtained from the 1920 simulations were processed using the statistical software R (Team 2014). The sensitivity analysis was conducted with the CALI cluster of Limoges university using OpenMole (Reuillon et al. 2013).

3 Results

Simulation results showed a clear increase of mean acidity observed after 50 years when the cooperative used policies (comparing bonus of 0 versus other values, Figure 5). More specifically, with increasing cooperative incentives the mean acidity increased whichever strategy was used (open or closed, Figure 5). However, even without incentives, acidity values arrived above the objective value of 3 $g \times L^{-1}$ of sulfuric acid (Bonus of 0, Figure 5) because of the limited space in low elevation areas. When looking at the effect of the cooperative behavior parameter (μ), with an open strategy, acidity decreased with an increase of μ. Thus, with this open strategy, there were contradicting effects of the bonus and behavior parameters. This illustrated the importance of incentive measures of the cooperative on acidity changes.

With the closed strategy, the acidity after 50 years was more limited between 3 and 4 $g \times L^{-1}$ of sulfuric acid than with the open strategy. This closed strategy penalized in the same way the vine-growers that produced vines above or below the objective of the strategy, and hence favors the possibility to reach this objective. Another important advantage of this closed strategy was that by forcing the vine-growers to select plots at altitudes for a given acidity, this decreased the variance of acidity among plots of a same simulation (Standard deviation in Figure 5). The decrease in variance is beneficial for the cooperative, as it indicates a decrease in the necessary temporal window for harvest.

The effects of cooperative behavior (μ) and bonus parameters on the proportion of vineyards plots were comparable to their effects on acidity (Figure 6). Indeed, with both strategies, for a given $\mu > 0$, an increase in bonus promoted an increase in the numbers of vineyard plots. For a μ=0 and an open strategy, the bonus increase stimulated the expansion of vineyards but only until 3000 €. Above this value, the expansion decreased. This is explainable through the comparison of the bonus value and the gains of harvesting a new plot (plot income - annual costs, see SM5). With this parametrization, the global behavior of the cooperative is not creating transition between rewards and penalty of too high acidity. Hence, for bonus values above 3000 €, the cooperative behavior (μ=0) blocked completely the expansion of vine-grower who had at disposal only areas

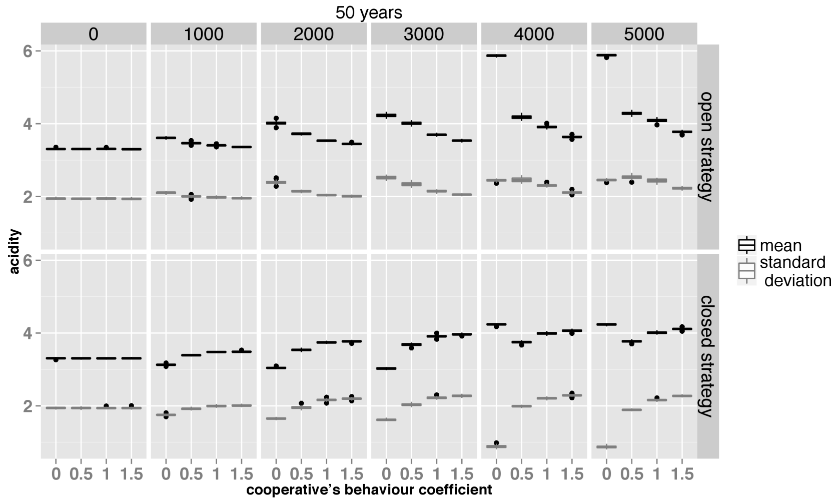

Figure 5: Mean and standard deviation of harvest acidity ($g \times L^{-1}$of sulfuric acid) after 50 years of simulations of climate change and different cooperative policies. The first line of graphs corresponds to the open strategy of the cooperative and the second line to the closed strategy. The cooperative behavior coefficient (μ) is on the x-axis of each graph, the maximum bonus/malus parameter (bonus) change for each column of graphs (given on the top). Boxes of the boxplot represent the distribution among the 40 simulations per modality.

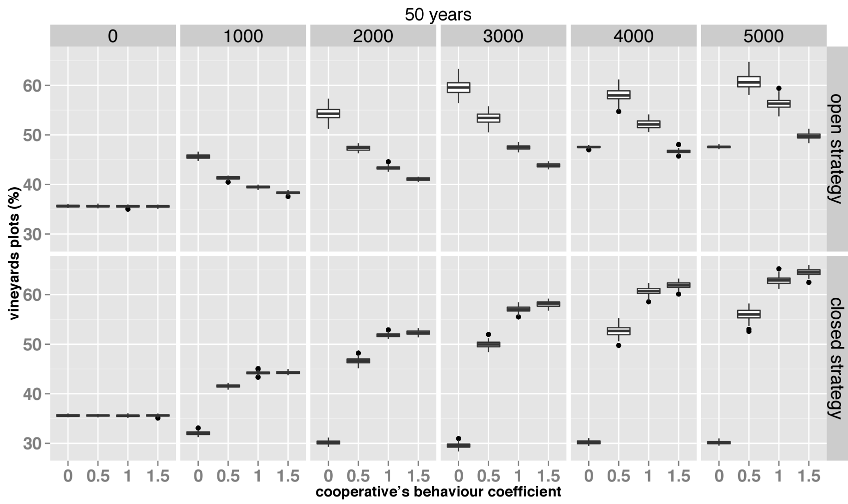

Figure 6: Percent of coverage on potential areas of vineyards plots in the landscape after 50 years of simulations of climate change and different cooperative policies. Organization of graphs as in Figure 5.

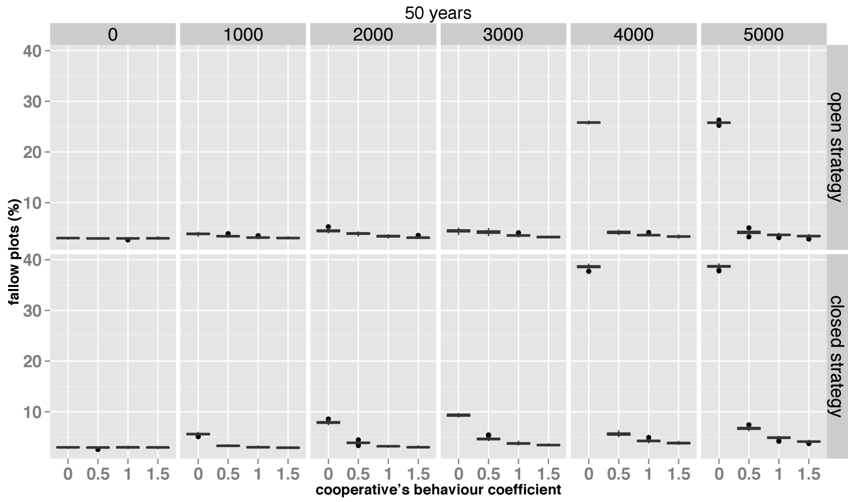

Figure 7: Percent of coverage on potential areas of fallow plots in the landscape after 50 years of simulations of climate change and different cooperative policies. Organization of graphs as in Figure 5.

of too low acidity. Keeping the open strategy, the increase of μ alleviated this binary response of the cooperative and consequently eliminated any apparent threshold effect (Figure 6). This allowed potential expansion of the cultivated area by vine-growers with time. Identically, in the case of a closed strategy, an increase in the behavior and bonus parameters increased the number of vineyard plots except with μ=0 (Figure 6). For a μ=0 and a closed strategy, the numbers of vineyards plots decreased with bonus increase. This was due to the categorical response of the cooperative with this parametrization. Plots of too high or too low acidity for the cooperative were hardly considered for expansion by the vine-growers. As a consequence, the cultivated area was reduced and constrained by the high penalty imposed by the cooperative (bonus value). Above 3000€of maximum bonus/penalty (bonus), the vine-growers were stopped in their expansion and forced to stay cultivating a relatively high acidity area. This actually explained why the acidity decreased slightly from 0€to 3000€of bonus and then jumped to higher values at bonus/penalty values above 3000€(Figure 5). For this specific case (bonus $>$ 3000€, μ=0, closed strategy), the imposed stop of expansion to vine-growers due to the high bonus/penalty values also created lots of fallow plots (Figure 7) and a landscape of very regrouped patches of vineyards, with low fragmentation index (Figure 8).

Fallow plots were always found on the landscape (Figure 7). Without policies from the cooperative, there was low numbers of fallow plots. With most behaviors of the cooperative, these numbers would not change much (Figure 7). The binary (μ=0) behavior of the cooperative (both with open or closed strategy) created more fallow plots due to the processes explained above. Increasing the μ and bonus parameters decreased the numbers of fallow plots. The fragmentation index illustrated the potential effects of the behavior of a cooperative on the changes in landscape configuration. As a general outcome, the

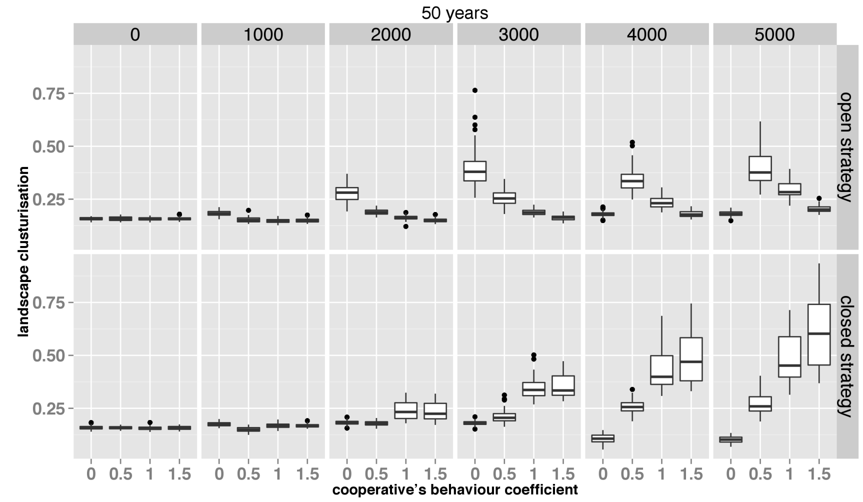

Figure 8: Fragmentation index of vineyards plots in the simulated landscape after 50 years of simulations of climate change and different cooperative policies. Organization of graphs as in Figure 5.

simulations showed that the higher the number of plots (Figure 6), the higher the fragmentation index (Figure 8). However, the median value of this index was always below 0.6, so relatively far from an indicator of dispersed landscapes (close or above 1). The change of results for maximum bonus/penalty (bonus) between 3000 and 4000€for the cooperative behavior of μ=0 was also discernible on the fragmentation index (Figure 6). With both strategies, this confirmed the forced stop of the expansion of vine-growers and their restriction to reduced but cohesive areas of the landscape as seen with the other indicators. With μ=1 or μ=1.5 and a closed strategy, the behavior of the cooperative do not lead to sharp decisions on leaving or buying a plot, and this also increased the fragmentation. The general trends of all these results were conserved after 100 years of simulations (Appendix B).

4 Discussion

Using an agent-based modelling approach we could analyze the potential evolution of a vineyards territory in a mountainous area under different cooperative policies. Our results showed that the mountain can be perceived as an asset to adapt to climate change. Moreover, we showed that cooperative policies can have impacts far more important on landscape and wine quality than climate change itself. This comforts the proposition of Lehmann et al. (2013) stating that local complexity can be drivers of adaptation to climate change. We demonstrated that the cooperative incentives can help in preparing to future problematic situations by anticipating the objective wine quality and driving vine-growers to use higher altitudes. In agreement with (Kelley et al. 2013), our results illustrate that the land use of vine-growers (or farmers) is very sensitive to cooperative incentives, which can be assimilated to a market behavior. We also observed that with specific cooperative policies, the time window of harvest could be conserved as a narrow window, despite climate change. The mountain then acts as a refuge to conserve reasonable harvest costs and wine quality.

The main outcomes of this study are more the patterns of evolution than the realism of simulation results by themselves. Indeed, the vineyard coverage is always expanding, despite the actual lack of dynamism on this area. Given these different results, we can focus on 3 scenarios that might be of interest depending on vine-growers and cooperative objectives. The first objective could be to increase mass production. In this case, the best scenario of cooperative policy is to have maximum bonus-malus between 1000 and 3000 euros and an open strategy with a binary behavior ($\mu = 0$). We observed that this open binary policy is useful to increase vineyards extension while keeping a low rate of fallowing plots. On higher values of maximum bonus-malus, the acidity stayed stable but variance increased, hence increasing wine production costs for the cooperative with a longer vinification time. With closed cooperative policies, the acidity was reduced but the production level was also lower.

An intermediary objective could be to find a trade-off between high quality and high production volumes. In this case, the cooperative policy should use a closed strategy with a gradual behavior ($\mu = 0.5$) and high remuneration rate (bonus at 5000€). This scenario of cooperative policy created, in our simulated system, acidity results a bit higher than expected but kept the variance low, meaning a low wine production costs for the cooperative. However, in this case, the vineyards are becoming heavily fragmented and the territory would then lose its emblematic landscape.

Finally, the objective can be to keep an emblematic landscape and produce hyper-valorized wines. In this case, the cooperative policy should use a closed strategy with low maximum bonus-malus incentives and a drastic penalization of acidities far from the objective ($\mu = 0$). This policy would keep acidity and its variance in actual values, develop the vineyards toward mountainous areas but conserve a homogeneous emblematic landscape. Kelley et al (2011) argued that a complex multi-strategy type of policies is the best to avoid landscape fragmentation. Our study supports this argument in the sense that the scenario complying with this objective is a relatively complex cooperative policy.

In the actual socio-economic context of the Banyuls-Collioure AOC territory, the first scenario is not credible. New wine-producer countries have the capacities to produce cheap wine with low labor costs (Schirmer 2005; Rouvellac 2013). The second scenario is in the continuity of current situation but might lead to an inversion of the territory (Hinnewinkel 2010). In other words, the qualitative zones on steep slopes would keep producing high quality but in low proportion regarding the territory. Indeed, for a vine-grower, it would be more interesting to produce a middle quality with reduced costs at low altitude. The choice of the third scenario would force the cooperative to find markets rewarding the efforts of the vine-growers with hyper-valorized prices. The quality and emblematic landscape being preserved, the commercialization would be easier (Alcaraz 2001; Sorbini and Macchi 2010).

These results need to be investigated further, particularly on the potential impacts of climate change on quality and phenology of grapes production. However, the Banyuls-Collioure AOC area is a territory with particularly good conditions for viticulture (Tonietto and Carbonneau 2004) and with a restricted numbers of climate constraints compared to other territories (Zhu et al. 2014). Hence, without waiting for deeper analyses, the present work illustrates that for such territories, local stakeholders have their own capacity to take measures to anticipate and adapt to potential climate changes. This confirms the proposition of (Van Leeuwen et al. 2013) that local adaptation is to be considered first. More particularly, it is important to avoid to condemn the existence of vineyards areas (as proposed by (Hannah et al. 2013)) as stakeholders can still, by themselves, find solutions to avoid the decline of their territory. The specific area of our study is not directly threatened by climate change thanks to the mountainous areas, and this give particular echo to our findings. Indeed, with these findings, there is still work to be done to bring together the stakeholders and let them realize the necessity to implement policies to favor quality and develop their products on a wine market that is everyday more and more competitive. Their cooperatives, as social focal point, are also important advantages for this territory, and similar ones in the South of France. Change of collective rules and in particular the deployment of policies using monetary incentives are difficult processes (Touzard, Draperi, et al. 2003). This need to be made in a clear and innovative framework, implicating all stakeholders, and with their conscience of the consequences of any orientation taken (Chiffoleau 1998; Touzard, Chiffoleau, et al. 2008). A solution in this context would be to pass from a "lab experiment" as defined by Robinson et al. (2007) and proposed in the present paper, to a "companion modelling" (Etienne 2013) approach to build collectively prospective adaptive solutions to climate change in a specific context.

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