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Scientific synthetical report

PN-II-ID-PCE-2011-3-0781 – PROIECTE DE CERCETARE EXPLORATORIE

Project IDEI 111/5.10.2011 "FOREST GHG MANAGEMENT"

Contractor
Institutul de Cercetări și Amenajări Silvice (05.10.2011-20.05.2015)
Institutul Național de Cercetare-Dezvoltare în Silvicultură „Marin Drăcea” (21.05.2015-03.10.2016)
B-dul Eroilor nr. 128
Jud. Ilfov

Project
Nr. 111 / 05/10/2011

Project code
PN-II-ID-PCE-2011-3-0781

Duration
05.10.2011 – 03.10.2016

Director
Olivier Bouriaud

Content

Visibility of the project's results

- Thanks to the methods developed or the equipment provided, the project contributed to support 3 PhD theses, one PhD being still undergoing:

  Mihai Lupescu, teză finalizată

  Turcu Daniel, teză finalizată

  Teodosiu Marius, teză finalizată

  Cosmin Bragă, în curs.

- 4 articles were published in journals belonging to the red list of UEFISCDI:

  Teodosiu M., Bouriaud O., 2012. Deadwood specific density and its influential factors: A case study from a pure Norway spruce old-growth forest in the Eastern Carpathians. Forest Ecology and Management, 283: 77-85

  Babst F., Bouriaud O., Alexander R., Trouet V., Frank D., 2014. Toward consistent measurements of carbon accumulation: A multi-site assessment of biomass and basal area increment across Europe. Dendrochronologia, 32(2): 153-161

  van der Maaten-Theunissen M., van der Maaten E., Bouriaud O. 2015. pointRes: An R package to analyze pointer years and components of resilience. Dendrochronologia, 35(1): 34-38

  Bouriaud O., Teodosiu M., Kirdyanov A.V., Wirth C. 2015. Influence of wood density in tree-based annual productivity assessments and its errors in Norway spruce. Biogeosciences, 12: 1-13

- Collaboration were supported, especially with Max Planck Biogeosciences (Jena, Germania) with which 3 articles were published, and with Wald Schnee und Landschaft WSL (Zurich, Elveția) (1 article under evaluation).
- One manuscript is under evaluation in the Nature group, which title or content cannot be disclosed here. The manuscript will refer to the project in its acknowledgements.
- So far 7 ISI and 10 BDI articles were published, and 2 more articles are under evaluation in ISI journals, 1 in a BDI journal.

- 2 BDI articles were published or are under evaluation in a recent journal, which is currently BDI but will soon have a ISI indexation: Forest Ecosystems, created in 2014. This peer reviewed journal belongs to the **SpringerOpen** collection, and is therefore open-access.

1. Introduction, Context

The importance of forests in storing carbon at global scale is not to be demonstrated. Even so the production of wood remains the main service expected from forests. Wood represents carbon that has been withdrawn from the atmosphere through photosynthesis, and is being temporally immobilized in the woody parts of the trees. It was recognized that European forests can act as effective reservoirs of CO_2, NO_X and NH_4. The determination of forest carbon stock is a priority for all countries participating in Kyoto negotiations.

Despite recent efforts, the contribution of forest ecosystems to store carbon dioxide is not precisely known, nor is their ability to capture and sequester carbon over long term. Forest management is more optimized for production of wood or environmental purposes such as protecting against various risk factors than for increasing the amount of carbon stored. The effects of management on the carbon stored, and more generally over the fluxes of greenhouse gaz, remains largely unknown.

2. Scope and objectives

The effects of forest management on forests' carbon stock and carbon storage capacity is less documented and is in the global objective of this project. FP7 project "GHG Europe" (www.ghg-europe.eu), funded by the EU, aimed to determine how, and to what extent, the carbon cycle and greenhouse gas emissions (GHG) emissions from terrestrial ecosystems can be managed. The basic idea is to manage GHG fluxes through terrestrial ecosystems management.

In this project, the Forest Research and Management Institute's mission is to study "The impact of land management on regional balance of greenhouse gas emissions in selected regions of Europe". Its task is to establish a gradient of management in beech forests to study the impact on the budget management of GHG. The gradient of management covers a wide range of management types but keeping confounding factors to a minimum.

The aim of the present project was to complete this management gradient with new unstudied situations in Europe, typical and relevant to Romania, namely natural forests and wooded pastures. The objective was to obtain data from experimental measurements GHG stocks and fluxes. The gradient of GHG project management built in Europe is developed for beech, a species widespread in Europe but which is the main species in Romania in terms of standing volume, thus having great relevance both nationally and at European level. Gradient followed currently consists of 12 areas, representative of typical forest management, contrasting with frequency and intensity of silvicultural interventions executed during the life cycle stands.

More globally the project aimed at estimating to what extent the different terms of the carbon cycle within the forest are being controlled by the forest management: the total stock, which can be proxied by the standing biomass of the forest stands, the productivity which quantifies and integrates the carbon sink strength of the stands, the soil respiration. Thus the project had activities aiming to study each of these factors.

The project has the following two objectives :

O1: the first is to analyse the dynamic of the aboveground carbon stocks in forests studied in order to contribute to the knowledge of carbon storage capacity in forests and the sensitivity to forest management. Special attention was paid to natural forests (e.g. Teodosiu & Bouriaud 2012), a novelty for the scientific community because of the rarity of this type of forests with limited availability.

Within this objective were developed the following research components:

1. Carbon stocks in forest ecosystems
2. Impact of the forest management over the C stocks
3. Management of the stand density
4. Retrospective or historical analysis of forest productivity

O2: the second objective was the monitoring of the greehouse gases in forest, mostly focused on the soil CO_2 fluxes. This monitoring is very time consuming and had not been realized so far in Romania.

Within this objective were developed the following components:

1. Methodological and technical aspects of the soil GHG monitoring using manual chambers
2. Analysis of the temporal divergence
3. Spatial variability analysis
4. Analysis of the management

3. Results

3.1 Carbon stocks in forest ecosystems

Forests store carbon in wood, wood being a long-term form of storage. But the wood is harvested and used to build products that sooner or later they will be burned or decomposed. Carbon stored in wood therefore returns to the atmosphere. A small fraction of the carbon remains in wood that will not be emitted into the atmosphere. This is why it was hypothesized that the natural forests do not contribute to the reduction of the CO_2 in the atmosphere: carbon stored in harvested wood and is intended decomposition. This idea has been generalized even for forests managed primarily for wood production.

In the context of managing greenhouse gases, this assumption is a negation of the role of forests and opportunities to contribute to the global effort to decrease the concentration of CO_2 in the atmosphere.

In the project were studied productivities spruce and beech forests in Romania, which were later compared with those observed (measured) in Germany for forests that similar ecological conditions. The comparative analysis has shown that the productivity of forests in Romania is much lower than that observed in Germany. Why productivity in Romania is not at the level of the German forests proved to be directly linked to forest management.

The study showed firstly that the biomass stored in stands of Germany is twice lower than in Romanian stands, but forest age is also much higher in Romania (Figure 1). The relationship between the volume per hectare and age was found to be very similar in fact, only the data in Romania are offset towards older ages by ~ 50 years.

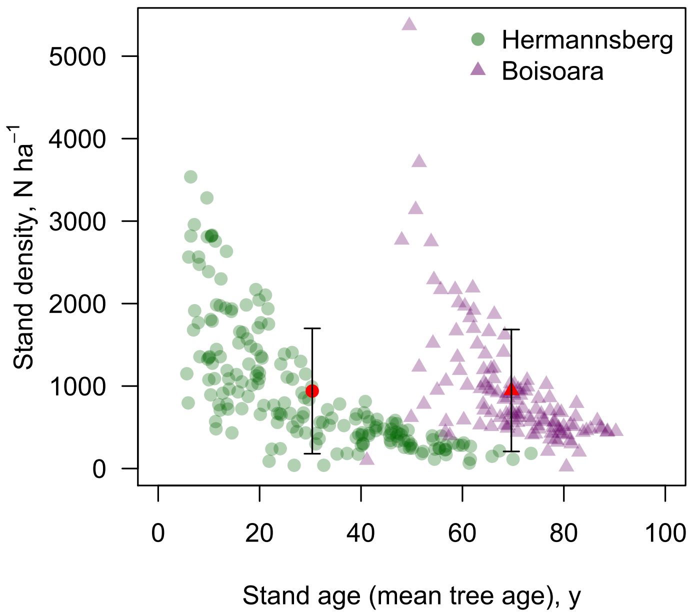

Figure 1. Stand density along stand age for the German (Hermannsberg) and the Romanian (Boisoara) sites.

The density of the stands in Germany proved to be a lot smaller than those of Romania for the same age: at about 30 years old, the density in Germany is lower than 1000 trees/hectare, while in Romania the density at 60 years still is over 1000 trees/hectare.

There is a very important gap in how to reduce the density of trees, which is a lack of care of young trees in Romania where practically tendering and thinnings are not made. Thus, the consequences are very high productivity: productivity in Romania is barely half the productivity observed in Germany. The results observed at the site level were confirmed at the country level (Figure 2) to be generalized local results were compared with values obtained productivity within national forest inventories. In Germany, spruce forests of 20-30 years have national productivity 19.8 m^3 ha^{-1}, while in Romania it is only 9.3 m^3 ha^{-1}.

The length of the production cycle practiced in Romania creates a second source of lost productivity: a cycle in Germany is 80 years, ie almost half cycle performed in Romania. Problems with the regeneration of the stands are observed in Romania because of advanced ages: the trees are too old to produce seeds in sufficient quantity and quality, which undermines the achievement of natural regeneration.

These results were presented in the article Bouriaud O, G Marin, L Bouriaud, D Hessenmöller, ED Schulze. 2016. Romanian legal management rules limit wood production in Norway spruce and beech forests. Forest Ecosystems 3 (1), 20

The results are very important and unexpected, they demonstrate that the forest management has an important and direct influence on the productivity of the forests. According to our results, the total amount of wood produced in the German forests, by unit of time, is indeed much greater than that of Romanian forests though the fertility of the forests studied was very comparable. This can be translated into a higher amount of carbon captured from the atmosphere and stored in wood.

3.2 Impact of forest management on the carbon stocks

The project FP7 GHG Europe aimed at exploring the effects of forest management on carbon stocks, and mostly relied on the data provided by the national forest inventory. The analysis was primarily focused on beech forests, since they represent the most widespread forest type in Romania, and this species has a great importance for the whole of Europe.

The study started within the FP7 project was continued and deepened, and various methodological issues have been improved, such as the aerial biomass quantification of stands studied, estimating productivity and the quantitative description of forest management. Thus, forest management was split into two factors, one being the nature silvicultural intervention performed, the second is the intensity of intervention. The project FP7 have been made some attempts to quantify the intensity interventions, but none were really conclusive. They were based on the relative density, defined by the laws of self-thinning, which is the maximum density that can support a forest stand without the natural mortality of individuals. The analyses carried out within the project ID enlarged analyses, including now the anthropogenic interference index named LUDI (Luyssaert et al. 2006).

These new analyses proved that (Figure 3):

- the aerial biomass or C stocks are not significantly influenced by the forest management regim;

- the aerial biomass or C stocks are not significantly influenced by the stand density. This result proves the fact that the successive harvests realised throughout the life of a stand do not reduce the total stock on the long run, because the stands build up the biomass very quickly;

- surprisingly the protected and unmanaged forests do not have a greater biomass per hectare than the production forests.

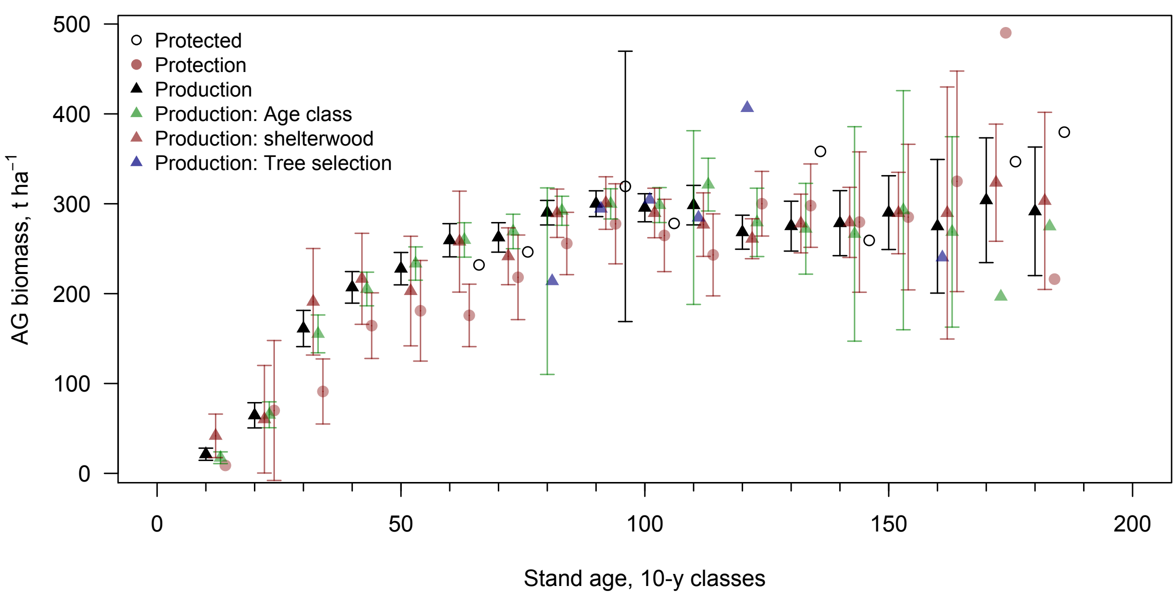

Figure 3. Comparison of the aboveground biomass stored in different types of forests, differing by their management type.

All these results are being presented in a manuscript which will be submitted shortly.

3.3 Management of stand density

These results are important because they open new possibilities for managing greenhouse gas emissions and fully justifies the project. Through this study we demonstrated that forestry in juvenile stages (early) results in higher productivity than those achieved when the silvicultural operations are made at a later stage. Harvesting of timber in juvenile stages refers to tendering and thinning. They are in most circumstances less profitable, not realized because the wood has a low economic value. Mechanization of these interventions is a very advantageous option, which is practiced long in the Nordic countries. Young trees, which are numerous and small, are very suitable for whole-tree havest operation. Young trees that cannot be put in value by classical methods can contribute to the supply of wood chips, which responds very well the growing needs of biomass for energy. The trees that remain in the stand increase their own growth as a result of the thinning achieved, and will compensate rapidly the decrease in carbon stocks produced by the harvest. Moreover the increased productivity will increasing the total amount of carbon captured by the end of the cycle.

The harvesting of wood is thus an efficient way to substitute for fossil-based products, but enables further to enhance productivity.

3.4 Retrospective analysis of forest productivity

The analysis of forest stands productivity has long been a subject of study since a long time window is needed to draw conclusions. There are only two alternatives: permanent plots or dendrochronological studies.

In this project the retrospective analysis is based on the methods developed within the context of the partnership with researchers from Switzerland (Babst et al. 2014). This method was applied and cited in several studies (e.g. Charney et al. 2016). After this article was also produced a review on global carbon cycle as seen in the light of dendrochronological series: A tree-ring perspective on the terrestrial carbon cycle, 2014 Ooecologia 176: 307-322.

The methodological limitations of the retrospective estimation of productivity were analysed through the project and have also led to the article O Bouriaud, M Teodosiu, AV Kirdyanov, C Wirth. 2015. Influence of wood density in tree-ring-based annual productivity assessments and its errors in Norway spruce. Biogeosciences 12 (20), 6205-6217.

4. Soil respiration

4.1 Methodological aspects

Through the project were developed recommendations on the sampling method greenhouse gas emissions from soil. Sampling method greenhouse gases can be applied without modification on any type of soil, including another type of land use.

Following project we concluded that chromatographic measurements are less effective and reliable than those of a portable device. Accuracy of the estimate flows detected gas chromatograph is however higher than that of a portable device. But storing the gas in vials is not a viable and reliable solution, especially for a duration exceed a week. We concluded that there is some loss even if the vial septum has not been punctured. In this context we recommend the use of carbon dioxide flux measurements using a portable device that does not involve storage of gas collected, so the technique using so-called dynamic cameras (Pumpanen et al. 2004). The only drawback is that the only greenhouse gas that can be assessed is the CO2, we loose the CH4 and NOx or other trace gase. Very low concentrations determined in the laboratory to nitrous oxide, which is recorded and literature (Eickenscheidt N. & R. Brumm, 2012), confirms the necessity of using an accurate gas storage field, which up to now has not successful. However the estimations over wide temporal and spatial flow of carbon dioxide from the forest soil using using a portable gas analyzer EGM-4 (PP Systems, USA) performed well, compared to other studies.

4.2 Analysis of the effect of management

Previous studies have shown a dependence between the stand density and the flux density of carbon dioxide which is related to the physiology of the trees. The competition for nutrients and light intensity correlated with the degree of development of trees constitute indirect factors affecting soil respiration.

During April-December 2015 were undertaken a number of 16 measurement campaigns in three different plots for which we intensified the silvicultural interventions (cuttings): control 0% forte I - 7% forte II - 14%. The measurements showed a low value of 0.8 μmol.m^{-2}.s^{-1} in April in SP1 (blank) and a maximum of 6.3 μmol.m^{-2}.s^{-1} in July to SP II (Strengths II). Moreover, the average value for CO_2 flux varies between 1.7 - 3.0 μmol.m^{-2}.s^{-1}, which is in agreement with other studies on comparable situations, such as Epron et al (1999).

The data obtained from the measurements campaigns suggest a slightly positive influence intensity intervention on rates of soil respiration. For example, in experimental area where the base area or volume is the highest value was an increase in the intensity of soil respiration due root biomass as well as favorable conditions for decomposition of organic matter. Effect separate abiotic factors (temperature and soil moisture) and biotic (by default forest structure and density distribution of roots and microorganisms activity) could not be assessed under the current methodology (C Braga, 2016). Thus it was deemed necessary to analyse the CO_2 fluxes in areas with indices of intensity largest but also to realize more complex analysis of soil properties, such as determining the root biomass, the heterotrophic respiration.

The project aimed at collected the data, and despite some technical difficulties, has been successful. The data have been partially presented so far in smaller manuscripts, but their compilation has been initiated and a more complex manuscript is under development.

4.3 Spatial analysis of the soil CO_2 fluxes

The analysis of soil CO_2 fluxes variability was based on an experiment whose purpose was to quantify the spatial variability in real conditions at the scale of a stand, or 2 ha. The main objective was to estimate the average flux and variance for a stand of beech of 85 years, considered representative for the project's studied stands. Throughout the stand the climatic conditions are homogeneous, and no spatial variability of past silvicultural interventions are noticeable.

A systematic network of plots was created, in the shape of a 25 x 25 m grid. At each node of the grid is a plot (considered as the primary sampling unit) consisting of 4 systematically located repetitions considered as secondary sampling units. CO_2 fluxes were measured at two occasions on the network: once at the beginning of the vegetation season (June) when soil moisture is still high, and once towards the end of the season (August) when humidity dropped. The measurements were carried out using portable gas analyzer EGM-4 (PP Systems. USA).

Together with the CO_2 fluxes were measured simultaneously the soil temperature of the superficial horizon (top 5 cm, because it is the most active) and soil moisture to a depth of 20 cm with a TDR 300 (Spectrum Technologies, Inc.).

4.4 Analiza datelor de derivă temporală

Since CO_2 fluxes measurements are rather slow and time consuming, the entire grid measurement for the spatial variability cannot be made over a single day, which raises the question of the existence of temporal drift. To test whether such temporal drift can hide or have interactions with the spatial variability, the measurements have included a specific analysis of drift. The principle is to measure repetitively and periodically the same plot, taken as a reference, throughout the campaign.

A sample of the surface network was repetitively measured during two days. The time series of the CO_2 fluxes measured are used to detect the presence of a trend. The measurements demonstrate that the values fluctuate around a global average (Figure 4) without displaying a visible trend or period. Standard deviations are quite high and confirm the idea of a random variability. Thus it could be concluded that there is no drift in time. So it is very unlikely that temporal variations during the campaign had an influence on the spatial analyzes.

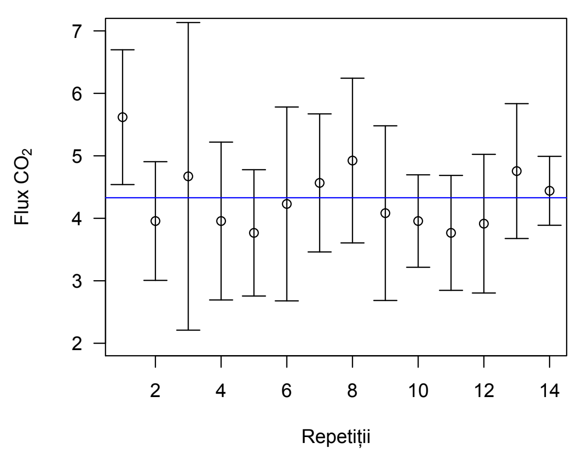

Figure 4. Analysis of the temporal drift: the measurement are spread over a global average (represented by the blue line).

Plot-level values are obtained by calculating a simple average of measurements made at each repetition. The mean value at the site level is similarly obtained by a simple average of the plot values. Despite the fact that the flux values are the result of several repetitions (N = 330), analyzes have shown that spatial variability is very high at both measurement dates. Thus, the coefficient of variation for the whole network is 37%. In June the average flux was 5.12 ± 1.06 $\mu mol.m^{-2}.s^{-1}$ and in August 6.41 ± 2.42 $\mu mol.m^{-2}.s^{-1}$ (± 1 Std Dev).

The first hypothesis so-called intrinsic spatial random variables is to have a uniform spatial distribution: expected value of the mean calculated on a randomly chosen group should be constant across the network. Spatial trends are therefore analyzed by simple linear regression methods. Fluxes did not show the existence of particular trends. The semi-empirical values of the variogram can therefore be computed directly, without correction (Figure 5). On both occasions the semi-variogram showed that the data do not have a spatial structure since the semi-variance is maximum or near maximum at the first distance class.

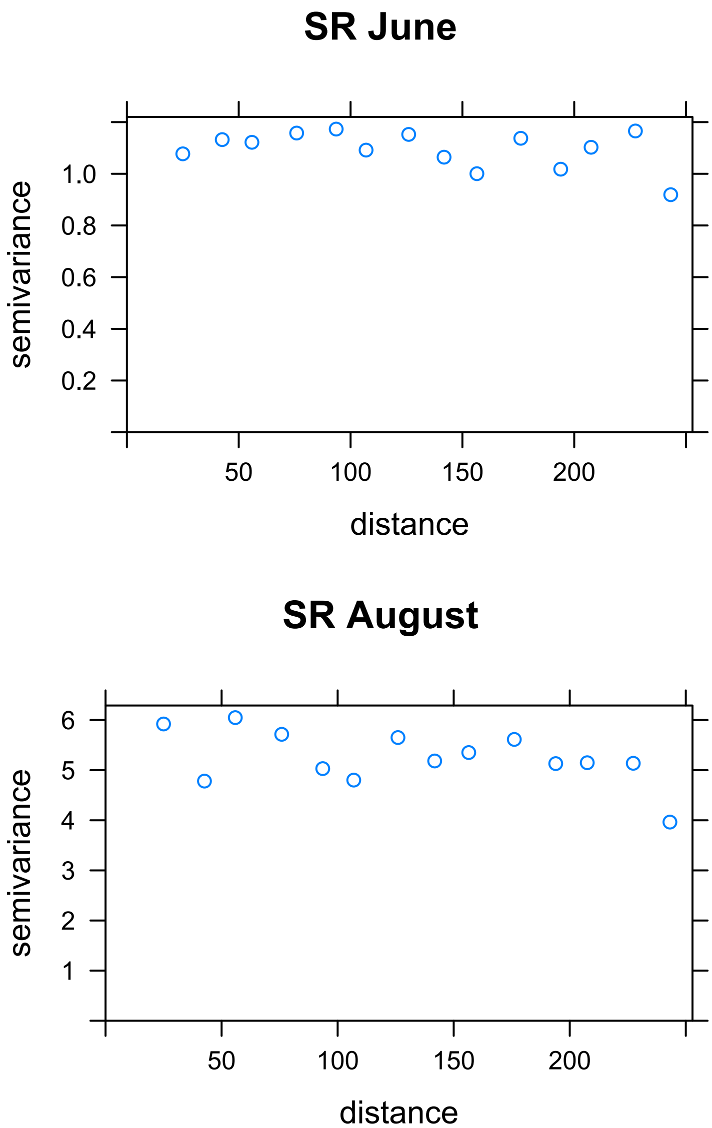

Figure 5. Experimental semi-variograms obtained from June and August measurements.

The analyses carried out by this experiment showed the very high degree of spatial variability of soil fluxes, and the absence of spatial structure. Conversely, environmental parameters such as the soil temperature and moisture have shown a clear spatial structure. More than the absence of correlation between flow and temperature or humidity values in the soil, it shows that soil CO_2 flux variability cannot be modelled or approximated spatially based on simple covariates. These measurements are continued and will be completed after the end project, to be used for writing an article.

The numerous flux measurements made in the experiment demonstrated the very high degree of variability in soil fluxes at the stand level. Calculating the number of sample plots that are necessary for the average value to be included in a range of ± 5% led us to a value of over 1,000 plots, which is practically not feasible.

5. Conclusions

The research conducted within the project have produced fundamental and conclusive results on the subject studied. Articles published in journals allowed to answer such questions addressed by the project:

- Is the greenhouse gas management possible? In the article Bouriaud et al. 2016 we demonstrated that the forest management contributes to increase forest productivity. Productivity determines the intensity of carbon sink capabilities. The harvest of trees increases the productivity and provides timber that contributes to reducing the use of materials and fossil fuels.
- The spatial variability of greenhouse gas fluxes from forest is so great that no direct, quantifiable effect of the forest management can be conclusively detected. This result is sustained in an article under review. The complexity and quantify the factors contributing to this significant process variability remains an important goal for future research.
- Concerning natural forests, the global effort produced in order to reduce the atmospheric CO_2 concentrations is limited to storing carbon. On the other hand, production forest, or forests used to provide wood and timber contribute also through the mechanisms of substitution.

The data collected within the project are further processed and new articles based on the project data and will refer the project in the Acknowledgement section. Beyond the data, the project was very useful because it brought bases for further studies, by defining working methodologies, by providing devices and equipment.

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