Final project report
Reporting template

Project acronym		WOODNET
Project title		Connectivity patterns and processes along a gradient of European landscapes with woody vegetation and spatial heterogeneity
Project coordinator	Person (Title, Full Name)	Dr. Jacques Baudry
	Entity (Company/organization)	OSUR CNRS France
Project period (Start date – End date)		Starting January 2017, ending November,30,2020
Project website, if applicable		https://woodnetweb.wordpress.com/

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List of partners involved in the project (company/organization and principal investigator). Please use partner numbers to specify the tasks, work packages and inputs of each partner in sections 4.3, 5 and 6.2 to 6.4.	Partner 1:OSUR France, Jacques Baudry Partner 2:UMP Spain, Partner 3:UCL Belgium, Thierry Hance Partner 4:UPJV, (edit as needed)

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Final report template for BiodivERsA3 funded projects

1. Short description for publicity

Provide a paragraph of text (max. 250 words) about the project and 2 photographs, to be used on the BiodivERsA website.

WOODNET (woodnetweb.wordpress.com/project-fr/) aimed at understanding the role of landscape elements dominated by trees (hedgerows, forest) in providing: habitat and means to move across landscapes; services to agricultural production. Our goal was to foster science based policies.

WOODNET relies on different sources of data: 1) remote sensing (satellite images and aerial photographs); 2) field observations of plant and bird, trapping of invertebrates; collecting indices of presence of bears and lynx; 3) experimental plots of plant transplantation; 4) genetic data from plants and insects and 5) the analysis of EU and national policies dealing with Green Infrastructures.

Key results: Remotely sensed data, as they produce quantitative metrics to describe landscape elements, improve prediction of species distribution in landscapes. Different images different results, major source of uncertainties. Lidar is useful to characterize forests, but perform poorly for hedgerows.

Remote sensing allows an accurate characterization of crop phenology.

Increasing connectivity of hedgerow networks fosters plant species with sexual reproduction, decreasing favors vegetative reproduction.

The impact of hedgerow networks on crop protection shows antagonistic results: increase of richness and abundance of beneficial arthropods in open landscapes; more slugs, aphids in close landscapes.

We explored and tested a suite of images and methods to assess habitat suitability and landscape connectivity for several types of species. A combination of images is useful.

Policy texts show a tension between the objectives assigned to GI: species protection and provision of ecosystem services.

Overall, WOODNET shows that interdisciplinarity between geomatics, ecology, policy scholars is fruitful.

	
Hedgerow network in Brittany (Air Papillon)	Dehesa in Andalucía (J. Baudry)

2. Summary

One-page summary (max. 400 words) of the key findings and impacts written for a non-technical audience, which BiodivERsA may use to give visibility to this project.

WOODNET (woodnetweb.wordpress.com/project-fr/) focused on the role of wooded features (hedgerow networks, forest, dehesa) in Western Europe (Belgium, France, Spain) in sustaining two ecological processes: movement of species across landscapes and crop protection by natural enemies of crop pests. We chose very different landscapes and species to cover a diversity of situations of landscapes and biodiversity stakes.

The production of maps has been an important part of the project, along with collecting biodiversity data. The maps were produced from different images taken from planes or satellites (Sentinel1&2, SPOT, Alos, Lidar, aerial photographs). This diversity was required for two different objectives: 1) testing which of the images available nowadays provide the best information to explain and predict species distribution and ability to move across landscapes and 2) how past landscape structure explained current species distribution. For the latter, only aerial photographs, from the 1950’ on are available

Biodiversity data were from different sources and of different kinds. Data on species came from 1) sampling into study sites, specifically for the project and 2) from long-term studies, collected by NGOs in charge of the protection of bears and lynx.

The main results are that Sentinel1&2 satellite images permit to produce good land cover maps, especially forests, as well as accurate maps of the dynamic of the phenology and biomass of wheat and oilseed rape.

The study of bears in the Cantabrian range shows that Sentinel gives good result in predicting presence. Lidar images are useful for both lynx in the dehesa and bear in Cantabria, because they give information of vegetation structure correlated with food availability.

In hedgerow network, we tested images with a higher spatial resolution. SPOT5 images were the best to predict the distribution of forest carabid species. The changes in connectivity since 1952 (assessed from aerial photographs) have no effect on species richness, but patches of habitat with a decreasing connectivity have more plant species with reproductive regeneration.

The results concerning biodiversity in crops are 1) there is some antagonism between conservation of species (some carabids) dwelling in hedgerows and beneficial arthropods for crop protection. Hedgerows favor slugs at field and landscape scales. Conversely, open field carabids are more abundant when the hedgerow network connectivity is low.

We also show that the heterogeneity derived directly from Sentinel images explains both crop phenology at field scale and carabid abundance. However, the effects changes during the growing season.

From a policy perspective, the very open definition of “Green Infrastructure” opens many possibilities, but it is also a source of uncertainties from an operational standpoint.

3. Objectives of the research

List major objectives (ca. half a page) in order of priority, as agreed at the award stage. Add new objectives as needed.

The scientific feedback to WOODNET had four points

1) **The new capacity to describe the internal structure of landscape elements from satellite images.**

The objective was to test the information brought by diverse satellite images (SPOT5, Alos) and air borne data (Lidar) to explain species distribution in wooded landscape elements (forest, hedgerows networks) as well as crops (wheat)

2) **Microcosm experiments for relating woodland connectivity to ecosystem services**

This experiment was put in place but failed

3) **Using historical maps to evaluate legacies of past connectivity.**

This was tested in two regions, over different time extent. Several centuries in Picardy and several decades inn Brittany

4) **Assessment of sources of uncertainty from the application of remote sensing to management of GBIs for biodiversity and ecosystem services**

We have shown that the results of the analysis of the interactions between landscape features and structures varies with the source of data used to map landscapes. Therefore, it is of utmost importance to describe the characteristics of the maps in landscape ecology. Anyhow, it is an important source of uncertainty to consider in policy implementation.

We added two items of importance for landscape management: 1) a broader objective to the study of remote sensing and crop phenology: the role of the heterogeneities of phenologies on crops at field scale and on biodiversity and 2) the definition of “ecolandscapes”, *i.e.* landscape units defined base on their composition and spatial patterns and we demonstrated that they harbor different type of species.

4. Project activities and achievements

4.1. General description of activities over the duration of the project

Factual description structured according to listed objectives, clearly specifying the input of each participant.
Circa 2 pages

Remote sensing

We acquired Terra-SAR images as planned for hedgerow network mapping, but the satellite cannot take several adjacent images on a site the same day. To Cover the Brittany site we had three images 11 days apart. They partially overlaid but, due to different level of vegetation humidity and frost, we could not produce a homogeneous map. Therefore, we acquired other data (SPOT, Alos, Lidar). Then we split image data into different classes corresponding to proxies of vegetation density (P1).
For crops, we articulated the analysis of Sentil1&2 images with field observations of phenology and biomass, in Rennes and Amiens (P1,4). They were used to calibrate the maps (P1).
In addition, we tested the use of landscape heterogeneity as deciphered by gradients from images (WDVI) to analyze its effect on field scale phenology and biodiversity (P1).
These activities were made possible by a PhD grant from the Ministry of Higher Education to Audrey Mercier (L. Hubert-Moy and J. Baudry, directors).

Other maps

In Brittany, maps from hedgerow networks and land cover were drawn from aerial photographs since the 1950.

Biodiversity data collection

In Spain, data on bears and lynx were obtained from organizations devoted to their preservation (P2).
In France and Belgium invertebrate data were collected in hedgerows and fields for WP1 and WP3. In the two French regions, we collected data on plants distribution and genetics of selected plants and carabids (P1,3,4).

Genetic data production

It is the part most affected by the pandemy, data collected (P4, 1) but genetic analysis is in progress (P4)

Data analysis

This task is, of course, crucial. It suffered from delays as landscape variables are derived from maps made from airborne data. That took a long time to finalize (P1). The development of novel metrics was done meanwhile (P1,2).
Data sharing went well.

Analysis of the legal aspects of Blue and Green Infrastructure

The activity carried out by the team of lawyers was essentially a desk job: an analysis of the legal texts applicable in European and national law with a focus on agricultural law. In addition to this analysis of the legal texts, work was carried out on the essential concepts a reflection on the relationship between law and science. In addition, two internships were supervised in this project: Alix Vollet on the concept of green infrastructure in law and Emnet Paulos on adaptive law (work supervised by A. Langlais and L. Bodiguel, CNRS). In addition, two ongoing theses have benefited to the project: Boryana Ravutsova, "Law and dynamics of agricultural landscapes: towards a rethought legal framework to fight against the loss of biodiversity in the agricultural environment", (work co-directed by F. Burel, DR, CNRS, ECOBIO and A. Langlais, CR CNRS, IODE) and Alix Vollet " Green infrastructure: from the European concept to internal legal operationality " (work co-directed by N. Hervé-Fourneau, DR CNRS, IODE and A. Langlais, CR CNRS IODE).

4.2. Table of deliverables

work packages	tasks	lead partner	initially planned	delivered	comments
WP0: project management	*0.1: Ensuring the coherence of the conceptual framework*	OSUR-France	continuously	done	
	0.2: Project meetings	OSUR-France	Nov-2016 Nov-2017 Feb-2018	March-2017 January-2018 March-2018	

	0.3:interactions with stakeholders at different scales	Each partner			Each partner has continuous interactions with the regional/national stakeholders
WP1: Relationships between landscape characteristics derived from remote sensing images and species distribution	*1.1:analysis of the characteristics of remotely sensed images for production of land cover maps*	UCL-Belgium **Changed** to OSUR FRance		done	As presented in the "difficulties", the Terra-SAR images could not be used. LiDAR images are analyzed and we started (in Rennes) to analyze ALOS images as radar data.
	1.2:analysis of the characteristics of remotely sensed images for the study intra and inter annual dynamics of vegetation covers	OSUR-France	January-2018	done	
	1.3 deriving metrics of vegetation and landscape structure from	OSUR-France	continously	done	Development of CHLOE-landscape metrics

	images				
	1.4: data collection and management for the Iberian lynx and brown bears	*UPM-Spain*		done	
	1.5: data collection and management for plants, carabids, damselflies, birds in hedgerows	OSUR-France	2017	Done	
	1.6: production of habitat suitability maps	OSUR-France	continuous	Partly done	
WP2: landscape legacies and species distribution	*2.1. Understanding the role of connectivity dynamics on biodiversity*	OSUR-France	2017	done	
	2.2 disentangling dispersal for recruitment limitation in hedgerow corridors	*UPJV-France*	2018	done	
	2.3: Measuring landscape	*UPJV-France*	2018	In progress	Genetic analysis are not finished

	connectivity: a landscape genetic approach				due to the COVID
WP3: agricultural landscapes connectivity and biological control services	*3.1: Evaluation of the population assemblages of species of interest for biocontrol*	*UCL-Belgium*	2017	done	
	3.2. Ecosystem disservices delivered by GBIs structure and Connectivity	*UCL-Belgium*	2017	done	
	3.3: Ecosystem services delivered by GBIs structure and Connectivity	*UCL-Belgium*	2017	Done	
	3.4: data collection for phenology and yield modelling	OSUR-France	2017	Done	Not for yield, only global biomass
	3.5: Overall impact of connectivity on pest damage and crop production	*UCL-Belgium*		Done	

WP4: Modelling connectivity and landscape resistance to movement	*4.1:Estimating landscape resistance from empirical data*	*UPM-Spain*	2018	done	
	4.2: connectivity modelling approaches	*UPM-Spain*	2018-2019	done	
	4.3: Spatiotemporal connectivity:	*UPM-Spain*	2018-2019	done	
WP5: the science/policy interface: Incorporation of scientific uncertainties into policies	*5.1: the legal challenges of building GBIs*	*OSUR-France*	2017	done	The planned seminars (interdisciplinary and comparative approach) have been carried out. The announced book is in progress, two articles have been written and two others in interdisciplinarity are being written.
	5.2: legal tools and flexibility for the implementation of GBIs	*UCL-Belgium*	2018	done	

4.3. Scientific outcomes

Describe briefly whether the objectives of the research (section 2 above) have been achieved and outline the principal outcomes of the work and their significance to the field.
Measure the results in relation to the project deliverables and publications, patents, etc. Revisit the state of the art and the stakes at the end of the project.
Up to 5 pages, with a few figures and tables.
Use partner numbers to specify the tasks, work packages and inputs of each partner.

WP01: Relationships between landscape characteristics derived from remote sensing images and species distribution (responsible: J. Baudry)

Task 1.1 & 1.2: analysis of the characteristics of remotely sensed images from Sentinel 1 & 2 images for production of land-cover maps and the study of intra and inter-annual dynamics of crop vegetation covers (responsible: L. Hubert-Moy)

Sentinel 1 & 2 permitted to produce maps of forest/ land cover vegetation as well as maps of crops (Wheat and oilseed rape) biomass and phenology. In both cases, we used ground observations. We also show that the images and methods developed for Europe can be used in a tropical context. Three papers are published.

Task 1.3: deriving metrics of vegetation and landscape structure from various images (responsible J. Baudry)

We developed novel metrics in the CHLOE-Landscape metrics software (https://www6.rennes.inrae.fr/bagap/PRODUCTIONS/Logiciels).
Connectivity metrics: clusters of pixels representing environment favorable for a species. It can be spatial connectivity or functional connectivity with the use of friction maps. These friction maps can be derived directly from the land cover mosaic or be gradients resulting from landscape structure analysis.
We also developed novel means to weight the different landscape components in analytical windows.

Task 1.4: data collection and management for the Iberian lynx and brown bears (responsible: M.C. Mateo-Sánchez)

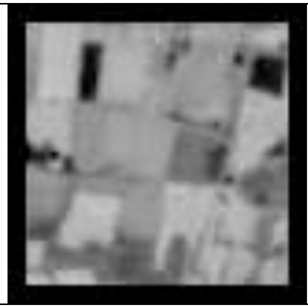
For the brown bear, existing species presence records and landscape genetic data available since 2000. For the Iberian lynx, telemetry data acquired through GPS collars between 2008 and 2015

Task 1.5: data collection and management for plants, carabids, birds in hedgerows (responsible S. Croci)

We collected the data, and the metadata are available of OSURIS

Task 1.6: data analysis of the relationships between maps of metrics and biodiversity data to produce habitat suitability maps (responsible L. Hubert-Moy, S. Croci, A. Alignier and J. Baudry,)

We compared the potential of maps constructed from Alos (SAR), SPOT5 (Optical) and Lidar to analyze the distribution of forest carabid in hedgerows. Two important outcomes are that 1) SPOT5 images (NDVI metric) are the most efficient and 2) considering only the densest parts of hedgerows (High NDVI for SPOR, High Biomass for Alos or High density of points for Lidar) gives better results than considering all information on the presence of hedgerows. This proves that the information content of satellite images is better than traditional land cover maps to analyze species distribution. The lesser performance of Lidar images, a costly information shows that a reflexion on a priori possibilities of the different type of images is needed.
This is also true for carabid species inhabiting crops. They respond to the heterogeneity of the WDVI metric of Sentinel2. We found that mapping the type of gradient is a characterization of the crop mosaic that can be used to compare landscapes without spending time to make land cover maps. Furthermore, these gradient data permit to understand intra-annual dynamics, what land cover mosaic maps do not.

			
Aerial view (2012)	Woody elements from SPOT	Sentinel 2: WDVI (phenological indicator) April 2018	

WP2. Landscape legacies and species distribution

Task 2.1. Understanding the main drivers of connectivity dynamics

The objective of this task was to analyze the relative effect of temporal dynamics of connectivity and habitat quality on plant assemblages. In a first analysis, we demonstrated that the dynamics of connectivity did not affect the species richness of the woodland assemblages. However, the magnitude and the variability of the temporal changes affected their traits. In woodlands experiencing upward connectivity trend, a high magnitude of the temporal changes in connectivity favored species investing into sexual reproduction at the expense of vegetative multiplication, while for a downward connectivity trend, the diversity of seed mass values increased.

Task 2.2. Disentangling dispersal from recruitment limitation in hedgerow corridors

We aim at testing whether forest specialists are usually absent from the most recent hedgerows, because of dispersal limitation (then sown seeds will germinate and potentially establish) and/or recruitment limitation (then sown seeds will not germinate) and/or persistence limitation (then transplanted plants will go extinct) due to poor habitat quality. Our results show that forest plant specialists appear to be not only dispersal-limited, but also recruitment-limited due to sub-optimal forest habitat conditions. Once established, most species hardly persist in recently planted hedgerows. Overall these results suggest that a high propagule pressure together with a high density of recruit are needed for long-term persistence of forest plant species in recent hedgerows.

Task 2.3: Measuring landscape connectivity: a landscape genetic approach

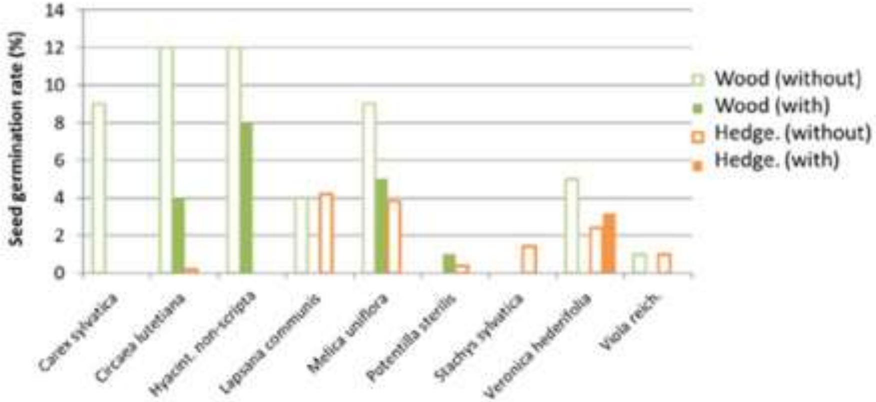
In this task, we quantify the landscape connectivity by estimating the functional connectivity reflecting gene flow due to dispersal. We explore the relationship between structural (WP1) and functional connectivity *via* a multispecies genetic approach comprising

- two plant species, one forest specialist *Primula* sp (*P. elatior* in Picardy, *P. vulgaris* in ZAA) and one generalist *Geum urbanum* characterized by a high and low dispersal capacity respectively;
- two carabid species, the forest specialist *Abax parallelepipedus* and the forest generalist *Pterostichus madidus.*

NOTE. Due to the Covid-19 outbreak, our work has been considerably delayed since the results expected in spring 2020 have been first postponed to July 2020 **but are not yet available at this time**. Therefore, the results presented here are preliminary with respect to (i) the genetic datasets, and (ii) the landscape component.

Preliminary results relative to plant model species show more genetic discontinuities in openfield than in bocage due to reduced gene-flow, reflecting a more limited dispersal capacity of all plants but especially P. elatior. Then, fewer hedgerows in a fragmented landscape would lead to lower biological connectivity, lower landscape permeability, limited dispersal enhancing greater genetic divergence between genetic units. Whatever the distribution and hedgerow network mesh size, hedgerows would permit frequent short-distance seed dispersal and occasional long-distance dispersal either through pollen (active dispersal) or seed flow (passive dispersal) for G. urbanum and P. vulgaris. They should also maintain the total genetic diversity in metapopulation. By contrast, where landscape is characterized by intensive agricultural practices associated with sparser hedgerow networks, hedgerows would

not offer optimal conditions for the establishment of P. elatior. Nearby populations of remnant forest fragments would be then extinction-prone if no gene movement occur into or out of those patchy populations**.**



Seed germination rates in hedgerows and the woodlot, according to the 2 treatments (“with”: with biotic competition, “without”: without biotic competition) in Rennes

WP03: The effect of wooded networks of biological control in crops: synergy or antagonism? (responsible: Thierry Hance, UClouvain, Belgium)

The objective of WP3 was to determine consequences of linear wooded networks on the service of pest biocontrol. As such, two groups of pests were sampled, namely aphids and slugs as an indicators of phytosanitary problems in agriculture. We also followed several groups of beneficial arthropods: carabids, spiders and aphid parasitoids.

Evaluation of the population assemblages of species of interest for biocontrol in relation with GBIs structure and Connectivity (Remote sensing and ecology)

We found a positive effect of the landscape grain on carabid beetle abundance and species richness. We found a negative effect on both spider and parasitoid abundance in early to mid-season, whereas the effect of the landscape grain was positive later in the season. On the opposite, the more the sampling point was surrounded by wooded areas, the lower was the abundance of carabids, and the lower were both the abundance and species richness of spiders (especially late in the season). Cultural continuity at year *n* had a negative effect on natural enemy abundances and species richness (especially in early season for spiders). An increase in cultural continuity in year *n-1* had a negative effect on carabid species diversity and on carabid abundance, especially in early and mid-season. All these results are discussed in a publication that should be submitted soon.

Ecosystem disservices delivered by GBIs structure and Connectivity

The results show that the density of slugs and aphids is higher near the edges of fields and more particularly near the hedge for slugs. Moreover, landscape grain had a negative effect on both aphid and slug abundances, especially at high cumulated degree-days. Higher wooded surfaces increased the abundances of slugs, especially late in the season.

Ecosystem services delivered by GBIs structure and Connectivity

The abundance of Carabid beetle shows a completely opposite tendency to that of slugs and aphids with a much higher activity inside the fields. This inverse correlation between the two activity levels is perhaps linked by a lower predation rate by Carabids near the hedge, this hypothesis will have to be verified. The hedges with their abundant vegetation and a wetter microclimate are also more favorable for slugs and can serve as a refuge to agricultural practices. A better regulation of slug populations appeared in landscapes where the connectivity of linear wooded elements is the weakest, that is to say, clearly landscapes that favor the species of carabids well adapted to open environments

In order to better quantify the activity of the parasitoids, in 2018, microcosms were placed in the crops at three distances from the edges of the crops in the landscapes characterized by a high and a low density of hedges in the same places. However, although this experiment required an impressive amount of work, the results obtained were disappointing and cannot be valued.

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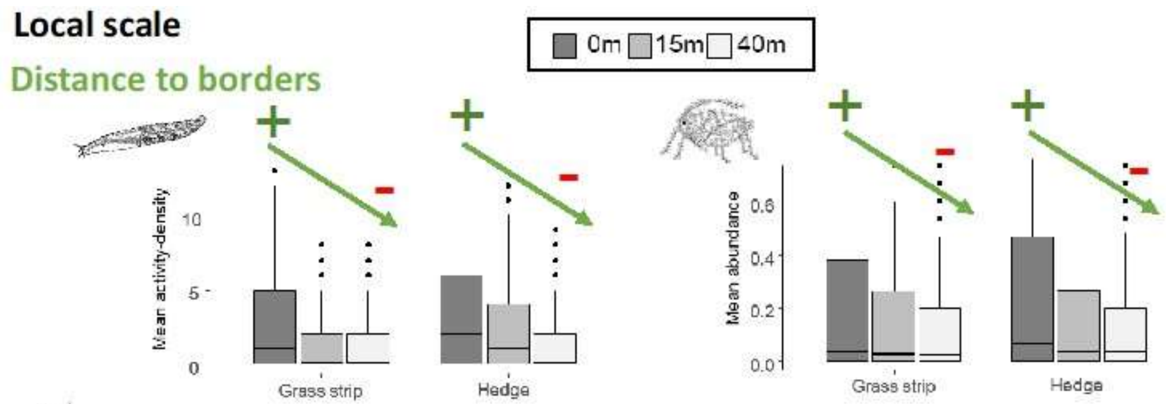
Overall effect of connectivity on pest damage and crop production

This task aimed at integrating the services and disservices due to the increase in landscape heterogeneity to draw new directions of landscape management combining both ecosystems services of biodiversity conservation by implementing a hedged network and biological control. Opposite predictions were made: 1) for slugs and weeds, an increase in heterogeneity and source habitat should increase their population while 2) Aphid abundance should decrease with and increasing presence of hedges because hedges may hamper the fly of alate aphid and their landing. The first prediction has been verified with a greater abundance of slugs near the hedges. On the other hand, contrary to what was expected, the quantity of aphids was also greater near the hedges. These results also showed a better regulation of slug populations in landscapes where the connectivity of linear wooded elements is the weakest, that is to say, clearly landscapes that favor the species of carabids well adapted to open environments. More particularly, slug activity-density and aphid abundance responded the opposite way from natural enemies to the landscape grain, mostly late in the wheat growing season. However, aphids seem to benefit from higher surface of wooded areas early in the wheat growing season. Later in the season, wooded elements had a huge negative effect on aphid abundances, probably because woods favour the presence of multiple predator species feeding on aphids. Wooded areas and hedgerows can also act as barriers increasing aphid abundances on the leeward of such obstacles, therefore preventing aphids from entering field crops. These results are the subject of a publication in preparation.



Slug and aphid abundances in relation with the distance to the hedges or to the grassy strips.

WP04: Modelling connectivity and landscape resistance to movement (responsible Thierry Hance)

A correct and empirically-informed parameterization of resistance surfaces is crucial to obtain solid ecological insights and efficiently guide conservation management measures. Landscape resistances were estimated in both brown bear and Iberian lynx study areas as an inverse of habitat suitability models fitted with occurrence and telemetry data. Different sets of land cover data were used as predictors. Each set of predictors represent common situations that data analyst may face as a result of different levels of availability of land cover data or financial and human resources for remote sensing analysis. For a given area, national or local detailed land cover maps (e.g. SIOSE in Spain) or continental scale maps (e.g. CORINE in Europe) may be available or not. Land cover classifications based in globally available remote sensing data (e.g. Sentinel) may be used anywhere, granted that technical resources to design and run classification algorithms are available..

We found some common effects of different sets of predictors on model performance in both studied cases. Adding the canopy cover and tree height estimations calculated using LIDAR improved model predictive performance measured through cross-validation. Our results show an increase in the Area Under Receiver Operating Characteristic Curve (AUC) of 7 % in the case of the Iberian Lynx (Gastón et al. 2019) and of 1.9 % in the case the brown bear (2.8 times more than the difference previously reported in Gastón et al. 2017). The observed increase may, however, respond to different mechanisms. LIDAR data helped to identify evergreen closed forests where the herbaceous layer can't produce enough biomass to allow high densities of rabbits that are the key prey of the Iberian lynx (Gastón et al. 2019). In the case of the brown bear, LIDAR data allowed a more accurate estimation of the amount of key foraging resources such as acorns, beechnuts and chestnuts (Gastón et al. 2017).

The effect in model performance of the predictors derived from Sentinel sensors showed more variability among study cases. Models fitted with a land cover classification developed for the Cantabrian Range using Sentinel 1 and 2 time series (WP1, Mercier et al. 2019) as predictor for the distribution of foraging and shelter resources for the brown bear showed a predictive performance similar to models fitted using CORINE land cover 2018 data and worse than the best models (i.e., national forest map combined with LIDAR). The Sentinel based classification could not discriminate among different dominant tree species and this issue may explain the lower performance compared to models where the species level data is available (e.g. Spanish Forest Map). However, as the model based on Sentinel data showed a good predictive performance (AUC= 0.90), using Sentinel data, that is freely available globally, may be the best option in many situations where detailed land cover maps are not available, neither at national nor continental scale. In contrast to the brown bear case, replacing national land cover data by a land cover classification developed using Sentinel 1 and 2 data resulted in an improvement of predictive performance (AUC increase of 4.7%).
The connectivity analysis conducted with the resistance surfaces derived inverting the predictions of those models showed very similar results, irrespective of the source of the predictors. The effective distances between brown bear locations through least cost paths calculated using Sentinel data were highly correlated with the distances estimated using the Spanish Forest Map combined with LIDAR ($r = 0.99$). Moreover, both resistance surfaces resulted in estimated effective distances highly correlated ($r = 0.95$) with those derived from a previously available independent resistance surface derived from genetic samples (Mateo-Sánchez et al. 2015).
Least cost path and circuit-based modelling represent two extreme movement modalities, optimal vs. near random. We, additionally, tested the Randomized Shortest Paths approach (RSP) that provides a continuum of modelling options in between these, with intermediate degrees of exploration and optimization (Panzacchi et al. 2015). Using Iberian lynx telemetry data, we searched for an optimum θ value. Although, the actual optimum θ may vary depending on the method used for the optimization and further research is needed, we have found a strong effect of the spatial scale of the analysis. If the optimization is conducted using a point selection approach, with GPS locations acquired every 4 hours, the optimum θ value is near 0, showing a habitat selection pattern near to random. The optimum θ rises to values nearer to 1 if a path selection approach is used, i.e., considering long dispersal events that may take days, weeks or months, suggesting a more optimal habitat selection pattern at coarser scales.

WP5 The science/policy interface: Incorporation of scientific uncertainties into policies (responsible A. Langlais-Hesse)

This WP looks at the place of GIs in the legal and political landscape in order to mirror this analysis with the state of scientific data and knowledge. The work package has been divided into two tasks, one dealing with the characterization of these GIs and the other with their implementation. These two tasks question, on the one hand, the scientific foundations of these GIs and, on the other hand, raise the issue of their legal operationally.

The characterization of GIs: we have based our reasoning on the definition adopted by the European Commission in the framework of its strategy entitled "Green Infrastructure - Enhancing Europe's Natural Capital". While recalling that there are several definitions of GIs, it defines them as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services". This stage was marked by an analysis of common terminologies to understand the terms of this European definition in the light of the conceptual framework of ecologists and legal work. Among these notions revolving around GI, those of ecosystem services, connectivity, functionality, nature-based solutions (Langlais, 2020) were examined. (article in progress).

The main result of this analysis tends to underline the existing tension between the objectives assigned to GI, *i.e.* between species protection and the provision of ecosystem services. The scientific analysis reveals a hiatus insofar as the identification of the provision of this range of ecosystem services requires an analysis of ecological connectivity, Indeed, the analysis of the ecological composition of GIs, the network, is based on methods and tools for species (e.g. permeability maps, remote sensing images to visualize the distribution of species, etc.). The expectation in terms of ecosystem services implies an additional level of analysis as well as an increase in the level of scientific uncertainty (the shift from analysis by species to analysis by services). Moreover, the design and management of GI depend on a hierarchy of objectives to be achieved or at least on a complex search for compromises. This can clearly lead to neglecting species protection in favor of more visible ecosystem services such as flood control.

This highlights the great variability in the forms of GIs due to the existence of a definition with a very open content but also due to the great legal latitude granted, which results in particular from the fact that the European strategy that conveys this notion is only a strategy, i.e. a non-binding document intended nevertheless to give impetus to a dynamic within the EU.

In a second step, we tested this consideration of the notion of GIs within the current and future CAP. If in the political discourse, the notion of agro-ecological infrastructures circulates, it is under another name that it is expressed within the CAP: landscape features. Undeniably, it occupies an increasingly important place in it, and this at different levels of normativity (in the first as well as in the second pillar). However, this greater consideration for GIs would have the effect of opposing desired biodiversity and imposed biodiversity. Finally, legal issues relating to the protection and management of these GIs in agricultural environments have arisen with regard to their management, their possible disappearance and, more generally, questions relating to ownership.(paper in preparation)

The implementation of GIs, two main results.
The first shows a correlation between the definitional contours of the GIs and the conditions of its implementation as an important source of scientific uncertainties. The diversity of scientific uncertainties was also highlighted. Therefore, a typology of scientific uncertainties is currently carried out with a view to distinguishing between scientific uncertainties that need to be eliminated and those that need to be preserved. This step is essential insofar as the law tends to globalize scientific uncertainties. These scientific uncertainties have thus been identified under three main categories: uncertainties linked to methods and tools, uncertainties linked to scientific controversies, and uncertainties inherent to science (the unknown unknown).

A second result concerns the treatment of these scientific uncertainties in design and the management of GI. Firstly, insofar as GIs are defined as "a planned strategic network", this invites choices of location and ecological objectives. However, these choices involve many variables. At the same time, the merits of such a definition offer a great adaptability to geographical, cultural, ecological contexts. To understand better these issues, we held a seminar going beyond the boundaries of European law to involve American and Canadian experiences. A book is currently being prepared to help broaden this "sharing of experiences" (Born, Langlais, Gordeeva, 2021). This adaptability also raises the question of the management of these GIs. To this end, the relevance of adaptive management has received a reserved response.

These two results imply treating the scientific uncertainties inherent to green infrastructures not necessarily as a gap in scientific knowledge to be filled and therefore to be dealt with through the prism of the precautionary principle, but in a differentiated manner. One of the challenges of a collective and interdisciplinary paper currently in progress is to give meaning to these scientific uncertainties, those correlated with the complexity of living organisms and therefore to legally consider the issue of heterogeneity (Langlais, Bergerot, Baudry et al., 2021). This work is essential in order to consider these green infrastructures as instruments in the service of socio-ecological resilience.

4.4. List of project meetings

Date	Place	Participating partners	Meeting title and object
2017/03/08-10	Rennes	All partners	Kick off meeting
2018/01/17-18	Amiens	All partners	Intermediate scientific meeting WP 1, 2 , 3
2018/03/19-21	Andujar Spain	All partners	Intermediate scientific meeting WP 4-5
2019/03/06	Rennes	WP5 partners (Rennes & Louvain)	Seminar: modes of representation of green infrastructure: Scientific and legal points of view
2019/10/09-11	Madrid	Madrid & Rennes)	Seminar on WP4 (connectivity)
2019/11/06-08	Louvain	All partners	Presentation of the results of all WP and preparation of the BIODIVERSA Meeting, Brussels, November
2020/04/28	visio	WP5 partners + EU representative + USA &	Seminar Incorporation of

Date	Place	Participating partners	Meeting title and object
		Canada partners	Uncertainties into Green Infrastructure (GI) Policy and Law.

4.5 Follow up activities and plans for further exploitation of the results

A large amount of data has been collected and the novelties in remote sensing open new perspective for data analysis. Genetic data will come, hopefully soon.
Numerous papers are under way; publications are expected next year.
The Spanish team propose to participate to a new project on connectivity.

The activities with the stakeholders will certainly grow as both conservation of forest, hedgerows and biocontrol are pressing issues and we have establish good connections.
In France the connection with CIRAD, The French agricultural research and international cooperation organization working for the sustainable development of tropical and Mediterranean regions, has open possibilities to connect landscape research between the temperate and tropical zones. (1 joint paper already publish and the PhD in remote sensing (P1) will start a post doc with CIRAD in February.

5. Stakeholder engagement in the project

This is a key point for BIODIVERSA, but the level of funding does not allow strong participation of stakeholders. Therefore, interactions with stakeholders are diverse, depending on previous, long-term collaboration and/or additional funding.

In Spain (Partner2), Brown Bear Foundation and the Regional Government of Castilla y León have provided presence data for the brown bear and have proposed sites to develop connectivity analyses in order to assess the potential expansion of the species in the Cantabrian Range. WWF-Spain and the Regional Government of Andalucía have provided GPS locations of the Iberian lynx and have suggested an enlargement of the study area in order to include strategic areas for conservation and restoration to enhance habitat availability and connectivity between stable lynx populations and reintroduction areas
Strong connections existed at the start of the project with both the bear and the protection groups. The latter gives information on WOODNET on its web site (http://www.iberlince.eu/index.php/esp/component/news/newsarticle/2563#.WrPlo38h2Uk)

In Brittany (partner1), connected to WP1&4, two Region and EU funds from European Development Funds (ERDF) projects permit important stakeholders involvement. The first is with the Regional Union of the Permanent Centers for Initiation to Environmental issues, CHEMINS (https://tvbchemins.com/) on disseminating information concerning ecological networks, the second is with the administrative unit of Lannion Trégor Community (LTC) in charge of planning ecological networks and the Hunter Association of Côtes d'Armor (Bocage and biodiversity group). The later led to the development of novel planning methods. It also foster collaboration with the National Geographic Institute (ING) on hedgerow mapping and hedgerow network analysis at the national level.

Dissemination of results during the annual meeting of the LTSER Zone Atelier Armorique and through popularization brochure (available online at https://osur.univ-rennes1.fr/za-armorique/)

In Belgium (P3), a committee of stakeholders has been set up to follow WP3 activities. It was composed of representative of Natagriwa, Natagora, Service Public de Wallonie-SPW, Département de l'Etude du Milieu Naturel et Agricole, SPW and of WOODNET Belgium labs.

The two seminars organized in the framework of WP 5 benefited from the participation of Stakeholders (representative of a public authority, Lise Debrye, in charge of the study "local urban planning" in Toulouse Métropole) and. The international seminar organized in the framework of WP 5 (P1&3) "Seminar Incorporation of Uncertainties into Green Infrastructure (GI) Policy and Law" has been announced on the European Commission *Emmanuel Pétel, representative of the DG Agri of the European Commission participated.* website: ec.europa.eu/environment/nature/natura2000/platform/events/uncertainty_and_multifunctionality.htm

5.3 Foreseen after the project's end

(e.g. preparation of new research projects, of stakeholder-led projects resulting from this research, etc.)

In France (P1), currently two scientific papers are in preparation with stakeholders as co-authors (Fusco et al; Defourneaux, Baudry et al). Not only did they collected and provided but also participate to the concept of the paper.
The BAGAP Lab of INRAE, a member of OSUR (partner1) started a new project with the Hunter Association of Brittany. Its aim is "to restore biodiversity in both hedgerow networks and fields in farms". We also continue to collaborate with the Nouvelle Aquitaine Region on preparing courses of continuing education on ecological networks. The collaboration with IGN is continuing within the "National Observatory of Bocages" in France.

For Belgium (Partner3) a meeting took placed on 11/17/2020 (by visio conference) with representants of the Research Center for agronomy in Wallonia (CRA-W), Members of the Liège University (ULg) and the Louvain university (UClouvain). The main goals of this meeting were 1° to establish a common data base on Carabid field sampling, including historical data; 2° to determine simplified protocol for determining the level of biodiversity in agricultural fields in relationships with agricultural practice with a focus on organic and agroecological practices, 3) Create a consortium of researchers. The idea of applying to the Belgian FNRS was launched to create a FNRS supported research groups in that field.

In Spain (Partner2), the collaboration with the stakeholders continues for the conservation of Lynx and bears.

6. Dissemination of results

6.1 List of scientific publications

Please use the dedicated excel template to report all the publications resulting from the project and follow instructions provided in the template.
Please also provide electronic copies of publications when submitting your report.

6.2. Dissemination of results to scientists and scientific organisations (1-page max)

Please describe the dissemination of results to scientists/scientific organisations, in particular listing all relevant (i) oral presentations, and then (ii) posters resulting from the project.

Please also indicate separately the initiatives taken by you to interact with other BiodivERsA funded projects. This list should include events organized by your project as well as participation in events organized by BiodivERsA or other BiodivERsA projects.
Use partner numbers to specify the tasks, work packages and inputs of each partner.

Congress Communication

Bergerot, B., H. Boussard & P-G. Lemasle From threshold-based methods to functional windows to characterize relationships between landscape variables and biological responses IALE World Congress, Milan, 2018

Francis, C.: Oral presentation during the Belgian agroecology meeting in Gembloux (14th November 2017) by. The presentation was about the WP03 in Belgium. – “Hedges and biological control”

Hecq, F. : Oral Presentation : Effects of wooded networks on biological control: synergy or antagonism?’ Landscape Ecology World Congress from 1st to 5th July 2019 in Milan (Italy).

Leroux, V.: Poster presentation by during the European Carabidologist Meeting in Rennes (25th-29th September 2017). The poster presented the WP01-02 and 03 of the Biodiversa Project “Woodnet”. – “Linking remote-sensing, biodiversity, connectivity and ecosystem services for ground beetles: the WOODNET project (2017-2019)”

Mercier Audrey, Laurence Hubert-Moy, Julie Betbeder, Joan Van-Baaren, Vincent Leroux , Jacques Baudry Assessing the wheat vegetation structure in space and time from local to landscape scale using Sentinel-1 and 2 time series and their use in ecology. IALE World Congress, Milan, 2018

van Baaren J, Barascou L, Hecq F, Le Roux V, Hance T. Influence du réseau de haies sur le service écosystémique. Congrès Entomophages Juan-Les-Pins 17-19 mai 2019

Van Baaren J. Behavioural and physiological responses of insects to climate change and consequences at the community level: the example of a host-parasitoid system in cereal fields. Drylands, 7th International Conference on Drylands, Deserts & Desertification: ***Feeding the drylands: challenges in a changing environment***. November 16-18, 2020 Ben-Gurion University of the Negev

Van Baaren J. The impact of climate change on insect life history traits and behaviours: consequences for biological control. Simposio Latinoamericano de Control Biologico. 8-10 Octobre 2019. Chillean. Chili. Conférence invitee plénière.

van Baaren J., Couthouis E, Barascou L, Pétillon J, Marrec R, Le Roux V, Hecq F, and T Hance. Interest of gradient studies to predict the consequences of climate change on conservation biological control. Communication invitée dans le symposium: Predicting population dynamics of insect pests under climate warming. XIX International Plant Protection Congress IPPC 2019, Hyderabad India, 10th -14th November, 2019.

Van Baaren, J; Couthouis, E; Barascou, L; Pétillon, J; Le Roux, V, Marrec, R; Hecq, F and Hance, T. Influence of spatial and temporal scales on the potential of biocontrol service of crop pests by their natural enemies through the analysis of activity-density and species richness. Aphidophaga Montréal 16-20 septembre 2019.

6.3 List of dissemination activities with stakeholders

Please list and describe any relevant publications, websites, interviews, and presentations intended for stakeholders.
Use partner numbers to specify the tasks, work packages and inputs of each partner.

6.4 Dissemination of results to stakeholders (1-page max)

- **Dissemination of results to stakeholders**: please describe individually significant interactions with state/federal agencies, industries, businesses, NGOs, managers of protected areas, etc. and other stakeholders to disseminate results from the project. Please specify as far as possible the number and names of people and/or organisations involved for each interaction, as well as the timing (before, during or foreseen after the end of the project).
- **Information / technology transfer**: please describe any specific information/technology transfer activities that have taken place relative to your *work.*
- **Outreach to the general public and Education project:** please list and describe any relevant publications, websites, interviews, presentations…

For WP1, Partner 1 had interaction with the groups of practionners mention above. In addition, a course on modeling landscape continuities was organized with Y. Coulaud of the “Assitance aus Continuités Ecologiques” (Assistance to ecological continuities of the Région Nouvelle Aquitaine. At IGN, the contact is Loïc Comagnac in charge of managing hedgerow network mapping we had three meetings.

Members of Partners 1 & 4) are associated with the Observatory of Bocage, coordinated by IGN (National Geographic Institute) and Office Français pour la Biodiversité (French Office for Biodiversity)

Baudry, J. Presentation at the 2018 annual meeting of the Fédération Nationael des Conseils d’Arcitecture, d’Urbanisme et d’Environnement dedicated to the “Trame Verte et Bleue” Baudry: “Les continuités écologiques dans les paysages agricoles. Montpellier, Feb, 2018
Baudry, J. Presentation at the 2018 sixth national meeting “Haies et Arbres Champêtres” (hedgerow and open landcape trees): Intercations netre les recherches sur les bocages et l’action publique (Interaction between research on bocage and public action). Lannion, 21-23 November
Bocage and Biodiversity group (2018) Elaboration d’un outil de diagnostic de la biodiversité des haies. Ministry of Environment, Observatory of Bocages, Novembre 2018.
Baudry, J. & Burel, F. La biodiversité des bocages s’évalue à l’échelle des paysages (Bocage biodiversity must be assessed at the landscape scale) Seminar of Observatory of Bocages, Niort.

We also produce a guide to consider landscape Structure and model ecological continuities in hedgerow network landscapes (Baudry et al, Guide méthodologique pour l’analyse des structures paysagères aux échelles locales Avec un focus particulier sur les continuités écologiques (in Woodnet articles)

7 Global Impact assessment indicators

7.1 Impact statement

Please describe impacts resulting from your work.

Although it is too early to evaluate the full impacts, at the end of the project, we can see some impacts

1) In the field of remote sensing, the paper on the use of Sentinel images published in 2019 has already 17 citations. The technique to produce land cover maps is used. Another point is that the shift from representing landscapes as mosaics to making maps of gradients seems promising. It reduces mapping uncertainties generated by the classification of gradients to types that are not sharply different. As Sentinel images are available everywhere and free, it is easy to compare landscapes with image metrics.
2) In the field of biocontrol, the common view that hedgerows have an important positive effect does not show in our results.
3) WOODNET stresses the urgency to consider scientific uncertainties in the design and implementation of Green Infrastructures

7.2 Synthetic figures for the project publications (including interactions with stakeholders)

Please indicate synthetic figures of project publications, including a summary and an analysis of project publications as follows (example):

8 published papers, 1 in revision, plus 1 submitted or in review and 22 in preparation (listed in the publication list template, but not taken into account in the following table). **1** published papers with impact factor **>5**, including Journal of Photogrammetry and Remote Sensing (1)

Analysis of the *project* publications:

Journal	*Current IF*	*Year of publication*	*# citations (2020_11_29)*
Journal of Photogrammetry and Remote Sensing	*7.3*	*2020*	*6*
Remote sensing	*4.5*	*2019*	*17*
Journal of applied remote sensing	*1.3*	*2020*	*1*
European Journal of Wildlife Research	*1.38*	*2019*	*3*
Land Use Policy	*3.68*	*2018*	*15*

Animal Conservation	*3.2*	*2019*	*1*

International dimension and multi-partnership for publications

Please indicate the number of single-partner publications involving only one partner, and of multi-partner publications that result from a common work.

Important: avoid artificially increasing the number of publications, mention only those that result directly from the project.

		Number of publications
Multi-partner publications	**Peer-reviewed journals**	2
	Books or chapters in books	
	Communications (conferences)	
Single-partner publications	**Peer-reviewed journals**	4
	Books or chapters in books	1
	Communications (conferences)	
Outreach initiatives including interactions with stakeholders	**Popularization articles**	
	Popularization conferences	
	Others	

7.3. Other scientific outputs

In this table, please list all outputs other than publications. You should give details on national and international patents, licences, and other intellectual property elements resulting from the project, etc. Please specify the nature of the outputs under the "others" section. These can be, for example, other elements of intellectual property resulting from the project than those listed in the table, launching of product or service, new project, contract, etc.

During the project, the software CHLOE-Landscape metrics (https://www6.rennes.inrae.fr/bagap/PRODUCTIONS/Logiciels) was completed with additional metrics regarding connectivity (modules CLUSTER and CONNECTITY METRICS). The software is being adapted to QGIS

7.4. Assessment and follow-up of personnel recruited on fixed-term contracts (excluding interns)

This table summarizes project recruitment of non-permanent personnel on fix-term contracts or equivalent. Fill out one line per person hired for the project
Interns who have an internship agreement with an educational establishment must not be mentioned.

Identification			Before recruitment for the project			Recruitment for the project				After the project			
Surname and first name	Sex M/F	E-mail address	Last diploma obtained at time of recruitment	Country of studies	Prior professional experience, including post-docs (years)	Partner who hired the person (Organisation and Country)	Position in the project (1)	Duration of missions (months) (2)	End date of mission on project	Professional future (3)	Type of employer (4)	Type of employment (5)	Promotion of professional experience (6)
Bas, Antoine	M			France		Université de Rennes2	Lidar engineer						
Mercier, Audrey	F	Mercieraudre2@gmail.com	Master2	France	none	Université de Rennes2	PhD student	36	November, 30, 2020	Has been recruited as a post-doc by CIRAD		Post-doc	
Defourneaux, Mathilde	F	Mathi.dfx@gmail.com	Master2	France	none	CNRS	assistant	4	November, 15, 2020	?			
Lemasle, Pierre-Gilles	M	pg.lemasle@gmail.com	Master 2	France	none	CNRS	Engineer	2	September, 24 2019,	Engineer LTEG	CNRS		
Ciudad, Carlos	M		PhD	Spain	5	UPM, Spain	Post-doc researcher	17	December 31, 2018	*fixed-term contract*	NGO	Technician	Yes
Cisneros, Pablo	M	pablo.cisneros.araujo@upm.es	MSc	Denmark	0	UPM, Spain	PhD student	12	March 1, 2019	PhD student	Teaching and public research	PhD Fellow	Yes
Goicolea, Teresa	F	t.goicolea@upm.es	MSc	Spain	0	UPM, Spain	PhD student	3	October 28, 2018	PhD student	Teaching and public research	PhD Fellow	Yes
Charlotte Francis	F	charlotte.francis.01@gmail.com	Master in Biology	Belgium	First employment	Université catholique de Louvain	Doctoral student	12	02/28/2018	Fixed term contract	NGO	Education	
Hecq Florence	F		Dr (PhD in sciences obtained)	Irland	Four years of Doctoral study, Trinity college do Dublin	Université catholique de Louvain	Post-doctoral	12	02/28/2019	Fixed term contract	Public Services of Wallonia	enginer	Data analyses and project managment

Table filling-out aid
(1) Position in the project: post-doctoral, doctoral student, engineer or equivalent, technician, individual contractor, other (specify)
(2) Duration of missions: indicate the total duration in months of the project missions carried out or planned

(3) Professional future: Open-ended contract, fixed-term contract, entrepreneur, still working on the project, post-doctoral position (abroad or not), student, between jobs, without any news
(4) Type of employer: teaching and public research, research public institution (EPIC), large company, SME/VSE, company creation, other public, other private, self-employed, other (explain)
(5) Type of employment: engineer, researcher, lecturer-researcher, executive, technician, other (explain)
(6) Promotion of professional experience: indicate whether the current position promotes the experience gained from the project

7.5. Data Management and timeline for open access

Please list databases, and indicate timeline for open access

All metadata will be available on https://accueil.osuris.fr/. The database management tool from OSUR. This insures a long term curation of data.

Furthermore, two data papers are plan to submit to Data-in-brief (https://www.journals.elsevier.com/data-in-brief). Therefore, data related to remote sensing and algorithms will be widely available.