PHUSICOS

According to nature

Deliverable D4.2

Evaluation of ecosystems and ecosystem services for alternative landscape scenarios with plan designs, draft

Work Package 4 – Technical Innovation to Design a Comprehensive Framework

Task 4.2 – Monitoring of ecosystem services

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Summary

The purpose of this partial report is to inform about progress achieved by the CREAF team in meeting the compromises included in WP4, "Technical Innovation to Design a Comprehensive Framework" during the first 18 months of the PHUSICOS project implementation.

Specifically, the document refers to the activities programmed to carry out Task 4.2, "*Monitoring of Ecosystem Services*".

The document compiles the list of indicators useful to assess effects on soil, vegetation, water, biodiversity and landscape of those NBSs included in PHUSICOS and intended to stabilize road cuts, to prevent snow avalanches and floods, and to minimize water pollution by soil sediments eroded from agricultural areas. The environmental relevance of each indicator and the simplest calculation methods are provided, together with recommendations for their inclusion in post-operation monitoring programs.

The report also includes detailed information about the NBSs to minimize hydrogeological risks in three points of the Spanish and French mountainous region of the Pyrenees, in an agricultural zone developed over desiccated peat soils in Italy (Massaciuccoli Lake, Lucca) and in a riverside area affected by catastrophic floods in Norway (Oppland County). For each case, the report explains the sampling campaigns carried out to assess the pre-operational value of the selected environmental indicators (their base-line) and proposes future scenarios to model the post-operational value of the indicators.

Contents

1 Introduction

The purpose of this partial report is to inform about progresses in meeting the compromises of the CREAF team included in WP4. Specifically, CREAF is at charge of Task 4.2 (*Monitoring of ecosystem services*) and cooperates actively in the fulfilment of Task 4.3 (*Co-develop monitoring systems for NBSs with stakeholders and experts*).

All NBSs proposed for their application to the study cases at each demonstrator site of the PHUSICOS project are intended to minimize hydraulic and geological risks. As these solutions entail local modifications of the local topography, hydrological characteristics, plant cover, soil and landscape, they also modify the environmental services provided by nature, and the resulting impact of this alteration must be assessed at the various temporal and spatial scales concerned.

In this sense, this document:

(a) Informs about the activities of the CREAF team until December 2019

(b) Describes in detail the current knowledge of the proposed NBSs at the PHUSICOS demonstrator sites, including the current state of the local environment and the expected post-operation environmental scenarios

(c) Goes deeper in describing the environmental indicators introduced in the D4.1. Deliverable about the "Comprehensive Framework for NBS Assessment", including their meaning and relevance, the simplest analytical approach and recommendations for a monitoring program

(b) Reports on progress in the assessment of the base-line of the indicators at selected study cases and about modelling their expected post-operational values.

1.1 Work structure and calendar

To calculate the environmental effect of the proposed NBSs within the deadline set by the project schedule, we designed the following five-phase work plan:

- ✓ Phase1. <u>Detailed study of the problems and NBSs proposed at each demonstrator site</u>. Since each solution is being co-constructed over time through iterative discussion cycles between researchers, technicians and local stakeholders, the final detailed designs are not yet available at the time of writing this report. Therefore, to proceed according to the agreed agenda, our staff has made several field visits to the demonstrator sites to generate "most probable scenarios" from which our indicator's tool box can be built-up (table 1).

Table 1. Calendar of the field visits and sampling campaigns in the demonstrator sites

	Barèges (France)	Biescas (Spain)	Serchio River (Italy)	Bastan River (France)	Jorekstad (Norway)
Prospective field visits	3-5/06/19 5-6/08/19	3-5/5/19 3-4/08/19	17-19/02/19	6/08/19	12-13/06/18
Sampling campaigns	22-24/09/19	25-27/09/19	28-31/10/19		

- ✓ Phase 2. Preliminary proposal of a system of environmental indicators. In October 2018, a first tentative list of environmental indicators was proposed for its inclusion in the D.4.1 PHUSICOS deliverable “Comprehensive Framework for NBS Assessment”. The list was constructed in close cooperation with the UNINA team and was based on consultation to experts. In October 15-17/2019, during a meeting of the PHUSICOS consortium in Lucca (Italy), this preliminary matrix was presented individually to the responsible of the demonstrator sites for selection of the indicators to be specifically applied at each site. Based on this selection, our researchers have been working in profiling the best methods to adjust these indicators to the specificities of each study case that can be found in sections 3.1.4, 3.2.4, 3.3.4, and 3.5.3. A detailed explanation of each indicator (meaning of the indicator, calculation method, recommendations for the monitoring plan) is presented in Section 4.
- ✓ Phase 3. Assessment of the base line of the indicators at each study case. The positive, negative or neutral effect of the NBSs on the environment must be assessed by comparing the pre-operational value of selected indicators (the indicators’ “baseline”) with their value once the measure has been implemented. In some cases, the indicators’ baseline may be extracted from recent surveys but, more often than not, this kind of data are unavailable at the detailed scale required for the project. Then, field inventory and sampling are mandatory. For this purpose, three sampling campaigns have been conducted in 2019 in the dates consigned in table 1.
- ✓ Phase 4. Calculation of the post-operational value of the indicators in the medium and long term. NBS implementation always cause abrupt modifications of the environmental parameters that describe the terrestrial (above- and belowground) and aquatic local sub-systems. Following the operations, the manipulated landscape is expected to evolve towards a new equilibrium in close dependence with local climate and surrounding ecosystem units. However, ecosystems evolve very slowly in relation to project timetables and, therefore, measuring the post-operational value of the indicators within the short time frame imposed by the projects does not provide reliable information on their response in the ecological short and medium term. To circumvent this pitfall, we have used two alternative strategies:

— When we have found landscape units fully representative of the predictable state of the ecosystem affected by the NBS in the medium and long term, we have sampled them for the selected indicators, and we have used the obtained values as proxies of the future state of the modified areas.

- When suitable proxy ecosystems are not available, the expected values of the indicators are being obtained from reliable theoretical models.

✓ Phase 5. Scaling-up the valuation at the landscape level. The assessment of the global effect of the NBSs on the selected environmental indicators will be obtained by extrapolating the values obtained from sampling and modelling to an adequate spatial scale. The current landscape structure has been obtained from satellite imagery and from pictures taken with drones, and the expected post-operational structure has been projected based on the NBS implementation plans at each demonstrator site.

In this partial rapport, we inform about progresses in the four first phases, since phase 5 is dependent on the total fulfilment of the previous phases.

2 Ecosystem indicators

2.1 Tool-box of indicators

Table 2 shows the tool-box of environmental indicators selected by for their use in evaluating the effect of the NBSs on watercourses, soil, vegetation and landscape.

Since not all these indicators are of use in evaluating the effects of every specific NBSs, the indicators selected for every PHUSICOS study case are considered in the specific sections of this report.

Table 2. Tool box of environmental indicators

ECOSYSTEM COMPARTMENT	CRITERION	INDICATOR	DIRECTION
Water	Biodiversity provision	Extended Biotic Index (EBI)	maximize
		Invasive alien species	minimize
	River quality	Fluvial Functionality Index (FFI)	maximize
	Water quality	Physical & chemical parameters	variable
Soil	Belowground C sequestration	Total organic carbon in topsoil	maximize
		Carbon sequestration: chemical protection	maximize
		Carbon sequestration: physical protection	maximize
	Physical resilience	Soil loss: water erosion	minimize
		Soil erodibility: aggregate stability	maximize
		Soil water holding capacity	maximize
	Fertility	Soil nutrients	maximize
		Soil texture	adequate
	Biodiversity provision	Carbon and nitrogen mineralization by soil food webs	maximize
		Ecosystem stability	maximize
		Microbial diversity	maximize
		Microbial functional diversity	maximize
		Invertebrate functional diversity	maximize
		Microbial community level physiological profiling	maximize
Vegetation	Aboveground C sequestration	Aboveground tree carbon stock	maximize
	Biodiversity provision & treats	Shannon Index	maximize
		Invasive species	minimize
	Soil protection	Total vegetation cover	maximize
		Non-Woody plant cover	maximize
	Wildfire risk mitigation	Plant Moisture Index	maximize
		Plant Flammability Index	minimize
Green Infrastructure	Landscape connectivity/fragmentation	Hanski's Index	maximize

2.2 Indicators' description

2.2.1 Water indicators

2.2.1. a. Extended Biotic Index

Definition and relevance of the indicator. The Extended Biotic Index EBI (Ghetti, 1997) is based on the qualitative analysis of the macrobenthic communities, i.e. those that live in close contact with the river bottom. These communities are mainly made up of invertebrates as insects, worms, crustaceans, leeches and molluscs. The index correlates the health of the river ecosystem to the different sensibilities of some macroinvertebrate groups. Both the presence or absence and the total number of systematic units (taxa) that constitute the macrobenthic community are indicators of the extent of environmental degradation and the presence of pollution. Its application allows to evaluate the degree of environmental integrity of a watercourse and to provide a particular biological quality class by awarding a score.

The use of macroinvertebrates to assess the effects of organic pollution of rivers has a long history throughout Europe and, although the detailed methodology might vary from country to country, their use for this purpose is well understood. In fact, this is the most commonly used element for biological classification of the European rivers. The sensitivity of macroinvertebrates to a wide range of impacts makes them a very useful tool for assessing river quality, although they are less useful in deep rivers where they may be difficult to sample.

Expected evolution of the indicator. It should be considered that the EBI, if reference conditions are correctly evaluated, detects any type of pollution which occurred during the life span of the organisms examined. In other words, even if the pollutants or disturbance are no longer present, the changes that they have caused on macrobenthic communities may persist for a few months. Therefore, the evaluation of the biological quality of flowing water by using the index EBI is a complementary tool to that of the traditional analysis of the chemical-physical parameters that evaluate water quality at the very moment in which the sample is taken.

Recommendations for the monitoring program. The EBI is an adaptation, for Italian waters, of the index presented by Woodwiss (1964). Although it is very well adapted for European water bodies, using the most reliable adaptation to specific regional water bodies is highly recommended. A list of similar and verifiable indexes for European Member States can be found in the *Monitoring under the Water Framework Directive* (2003). It is recommended to perform annual updates in the base of quarterly evaluations.

Analysis method. The gathering of invertebrates occurs through a net with a handle and is performed by sampling at different points within the water course so that all the different habitats are examined; the collected sample is preserved by addition of formalin and analyzed in the laboratory using a stereomicroscope. Each collected specimen is identified at the systematic level (genus or family) requested by the method. The determination of the EBI value is based on a double entry table: the rows have as headings the different groups of macroinvertebrates listed in order of decreasing sensitivity to environmental changes; the columns have as headings the ranges of the total number of systematic units than can be found in the samples. The EBI score is obtained by crossing the line corresponding to the most sensible systematic group with the column of the number of systematic units found. The score corresponds to a water quality class and represents a synthetic valuation.

2.2.1. b. Invasive alien species

Definition and relevance of the indicator. In line with the provisions of the European Strategy on Invasive Alien Species (2004), one of the most effective tools for the fight against invasive species is the organization of an early detection and ready response system (EDRR or rapid response protocol), which allows timely intervention on new populations which are settling in a territory. Moreover, the number of invasive species present in any river ecosystem (principally invertebrates and fishes) is a good indicator of the level of alteration undergone by the water body.

Disturbances related to human presence, from commercial vectors to leisure (fishing releases), are the principal source of invasive species. However, also environmental alterations as floods and drought can create the necessary window of opportunity for the development of invasive communities. In any case, in the event of early detection, the inclusion of an EDRR is highly recommended, aside from the original evaluation program.

Expected evolution of the indicator. As described in relation to macroinvertebrates, the number of invasive species detects any alteration which occurred in the life span of the organisms examined and beyond. Even if the original disturbance has ceased, the changes caused on microbenthic and fish communities may persist for a long time.

Recommendations for the monitoring program. An exhaustive and confirmed list of invasive species for European inland waters can be found in Gherardi et al. (2009). Although the list is very reliable, it is highly recommended to use its closest and most up-to-date adaptation to specific regional water bodies, since invasive species are in constant evolution and their potential risk to the environment varies locally. It is recommended to perform annual updates in the base of quarterly evaluations.

Analysis method. Different groups of animals must be sampled and evaluated in different ways. Macroinvertebrates can be sampled through a net with a handle as previously mentioned for the calculation of the EBI (section 1.1.a). In the case of fish, specific net captures must be performed, which can also be useful in order to answer one of the questions within the Fluvial Functionality Index (see section 2.1.1.c).

2.2.1. c. Fluvial Functionality Index

Definition and relevance of the indicator. The Fluvial Functionality Index, FFI (APAT, 2007) evaluates the capacity of a waterway to resist pollution and self-purify through a series of parameters that concern the riparian and aquatic ecosystems; the riparian vegetation and related structures act as a natural filter for pollutants entering the basin, while the hydric compartment has the ability to degrade the pollutants. Both the filtering and the self-purification capacity are more efficient in reference conditions, which are supposed to be closer to natural conditions.

Rivers are increasingly subjected to numerous interventions of morphological modification (as hydraulic regulation works, bridges, dams, urbanization, etc.) which, together with the increase of pollution, determine a progressive denaturalization and deterioration of the river environment quality. The increasingly frequent water crises show the ecological, economic and social limits of the single-objective perspective of considering water a waste to be disposed of, rather than a wealth to be retained on the territory. All these elements are linked by balances and functional relationships that are the subject of river ecology, but are difficult to translate into concrete approaches and tools directly and easily used by operators involved in environmental monitoring. The FFI provides a rigorous but easy to use tool, to read and understand these relationships with the aim of recover, as much as possible, that ratio of positive functionality between rivers, man and territory.

Expected evolution of the indicator. Reference conditions are key to understand the FFI, since the index derives from the answers provided by the indicators and are then affected by their characteristics, placing themselves on different levels of operation. Bio-indicators, involving multiple levels of the biological organization, are placed on different hierarchical levels in a scale temporal and ecological relevance. Therefore, there are indicators characterized by a short response time and low ecological relevance (as biochemical) and others that have a long response time, but a high ecological relevance (as for example, responses at the community level).

Recommendations for the monitoring program. The FFI is an adaptation for Italian waters of the RCE index (Petersen, 1992). Although it is very well adapted for European water bodies is highly recommended to use the most reliable adaptation to specific regional water bodies. As many of the characteristics of the FFI are landscape dependent, there is no need to repeat the methodology with a constant frequency. However, as mentioned before, it is important to define what is considered as reference conditions or which the objectives of the evaluation are in order to specify which landscape changes merit a second evaluation. In any case, it is recommended to perform the evaluation along a reach of 150 m per watercourse.

Analysis method. The degree of naturalness is determined through a card with 14 questions related to the same number of environmental parameters: 1) state of surroundings, 2) vegetation belt, 3) size and, 4) continuity of functional structures, 5) hydric conditions, 6) flooding efficiency, 7) riverbed substrate, 8) erosion, 9) transversal section, 10) fish fitness, 11) hydro-morphology, 12) riverbed vegetation, 13) detritus, and 14) microbenthic community. In order to apply the method, the operator has to go on the stream to be investigated, and must assign the scores on the basis of the observations required by the tab. Then the sum of these scores is carried out and a final result can be translated into a corresponding class quality and in the respective judgement of quality. Some parameters must be evaluated separately for the two shores, and therefore may provide two different final judgments.

2.2.1. d. Physical and chemical parameters

Definition and relevance of the indicator. Physical and chemical quality elements (principally temperature, nutrients, salinity and pH balance) are basic measures of river condition and important influences on natural river systems. It is important to include measurements of these elements in relation to their natural as well as potential polluting influences. For example, nutrient concentrations outside the expected range are likely to cause eutrophication. Other main quality elements that need to be taken account are the specific pollutants identified as being likely to cause a failure of the biological quality status. These will vary locally and will need to be determined during the analysis of pressures.

Physical and chemical characterization include water temperature, dissolved oxygen and oxygen concentration (expressed in mg/l and in saturation percentage respectively), the pH values and the electrical conductivity (expressed in micro Siemens /cm), and finally the presence of different nutrients in ppm (a ppm is equivalent to a part by weight mineral in a million parts of solution).

The following descriptions presents the most useful parameters based in the *Monitoring under the Water Framework Directive*, considering the pressures to which each parameter respond, the principal sources of variability, and the main methodology.

Thermal conditions (temperature). Responds to inflows, water releases and industrial discharge pressures, and is of crucial importance for the assessment of biocenoses. Temperature is influenced by daily changes due to respiration (with lower variation in fast flowing rivers). Monitoring should consider seasonal stratification and mixing (in deep water) and cold water releases. Sampling should be performed in-situ using submersible probe, fortnightly/monthly during all seasons, by a single measurement or water column profile.

Oxygenation conditions (dissolved oxygen; mg/l and % saturation). Responds to organic pollution and industrial discharge pressures, and is central in assessing the biocenoses. It is influenced by climatic conditions. Monitoring should consider seasonal and daily variations. Sampling should be performed in-situ using submersible probe or sample collection and Winkler titration, fortnightly/monthly during all seasons, by a single measurement or water column profile.

Salinity (conductivity, sodium, magnesium or calcium concentration). Responds to agricultural runoff and industrial discharge pressures, also recommended in rivers in semi-arid climate and/or with high salinity. It is influenced by water flow. Monitoring should consider seasonal stratification and mixing in deep waters. Sampling should be performed in-situ using submersible probe, fortnightly/monthly during all seasons, by a single measurement.

Acidification status (pH, acid-neutralizing capacity, alkalinity). It responds to industrial discharges and acid rain pressures, and is also recommended in rivers with risk of acidification. It is influenced by buffer capacity, water flow, etc. Monitoring should consider seasonal variations. Sampling should be performed in-situ using submersible probe and sample collection, fortnightly/monthly during all seasons (special attention during sea salt or snow melt episodes), by a single measurement.

Nutrients (Total P, Total N, SRP, NO_3^+ NO_2, NH_4). They respond to agricultural, domestic and industrial discharge pressures, and are very important indicators for human activity and eutrophication. At least total N and P, nitrate and orthophosphate should be monitored. Ammonia must be monitored where concentrations are expected to be problematic (e.g. exceedances of limit values over a specific limit). Nutrients are influenced by land-use, buffer capacity, temperature /oxygen demand, presence of binding metals, etc. Monitoring should consider sources (diffuse/point pollution), and demands enough chemical speciation as to enable source discrimination. Sampling should be performed in field followed by laboratory analysis, fortnightly/monthly (more frequently during flooding) during all seasons (particularly following inflow events. Not during ice cover), by a single sample, or profile in deep waters.

2.2.2 Soil Indicators

2.2.2. a. Total organic carbon in topsoil

Definition and relevance of the indicator. The total soil carbon (C) pool is the sum of three carbon forms: elemental C (graphite and soot derived from natural or anthropogenic incomplete combustion), inorganic (mostly carbonates and bicarbonates) C, and organic C.

Organic carbon is the main component (58% in average in topsoil) of soil organic matter (SOM) and is often used as a proxy for it. SOM is made up of plant and animal materials in various stages of decomposition, of microbial cells and microbial products, and is vital for soil to maintain its functions and to correctly deliver its ecosystem services. SOM turnover plays a crucial role in soil fertility, terrestrial ecosystem functioning and global warming mitigation. Organic matter is critical for the stabilization of soil structure, retention and release of plant nutrients, and maintenance of water-holding capacity and, hence, is a key indicator for agricultural productivity and environmental resilience (Lefèvre et al., 2017).

After organic matter from plant and animals enters the soil, it is mineralized by soil microorganisms. The resulting mineralization products can persist in the soil for variable time periods (spanning from decades to millennia), but a fraction of the soil organic C is emitted back into the atmosphere as CO_2 or CH_4, is lost as eroded soil material, or is exported to surface and underground waterbodies as dissolved organic carbon.

Globally, SOC (soil organic carbon) stocks are estimated at an average of 1500 PgC (1 PgC = 10^{15} gC) in the first meter of the soil (Scharlemann et al., 2014), which is more carbon than is contained in the atmosphere and terrestrial vegetation combined (FAO & ITPS, 2015). For all these reasons, SOM (or SOC as a proxy) is a fundamental parameter in the calculation of soil quality indexes and is always included in post-restauration monitoring programs (Mukhopadhyay et al., 2014).

In Europe, the organic carbon content in the topsoil ranges from <1%, in degraded soils and natural soils of the arid and semi-arid zone, to > 40% in organic soils mainly located in the northern cool and wet regions (de Brogniez et al., 2015) and also in peat soils under warmer climate (see the case of the Massaciuccoli study case in this report). Land use and management dramatically alter SOM content and dynamics and can made of soil a carbon sink or a carbon emitter (Lal et al., 2015).

Expected evolution of the indicator. Land use intensification and land degradation result in losses of soil organic carbon (Matson et al., 1997), and highly degraded terrestrial ecosystems typically have soils with low organic carbon content. Inversely, soil quality assessment of post-restauration chronosequences shows that soil organic carbon increases with reclamation time as vegetation recovers (Mukhopadhyay et al., 2014). Therefore, in our study cases, soil organic C is expected to increase over time in the area affected by the NBSs. As ecosystem recovery progresses, the SOC values in these zones are expected to converge with those measured in the mature land units chosen as references for the long-term scenario.

Recommendations for the monitoring program. Follow the evolution of soil organic carbon every 5 years.

Analysis method. Soil organic carbon is measured from soil samples taken at 0-15 cm depth. Before analysis, the samples are air-dried, homogenized and sieved at <2mm. The analytical process starts with the elimination of all inorganic carbon by acidification of the sample. The resulting product is then totally oxidized by combustion with pure oxygen at about 1000 ºC. The resulting CO_2 is transported by helium, separated in a selective column and measured in an elemental micro-analyzer.

2.2.2. b. Carbon sequestration in soil: chemical protection

Definition and relevance of the indicator. Soil organic matter mineralization (or "decomposition") is the consequence of microbial nutrition and metabolism. Heterotrophic microbes exploit soil organic matter as a source of energy and, as a result of their metabolism and respiration, the SOM-C is released as CO_2. The quantity of carbon respired as CO_2 per unit of soil weight and time is the SOM decomposition rate (*k*) that highly depends on microbial biomass and activity and on SOM quantity and quality. In this context, SOM "high quality" is equivalent to SOM "lability", or SOM suitability to be quickly exploited by soil microbes. Inversely, SOM "low quality" is equivalent to SOM "recalcitrance" or SOM resistance to be decomposed by microorganisms.

SOM is composed by a great variety of chemical forms of different decomposability and, in short, three different fractions may be identified: (a) a small (1% to 5% of total SOM) but very active *labile* pool that is very actively utilized by the micro-organisms; this fraction originates from new residues and living organisms (including dead micro-organisms) and has a turnover within 2 – 3 years, (b) a *slow* fraction, with a turnover of 20-40 years, consisting of organic compounds that are either chemically resistant to decomposition or physically protected, and (c) a large *passive* fraction chemically stable with a turnover greater than 2500 years.

The labile fraction is extremely sensitive to changes in plant composition and activity, climate and management, the slow fraction is very responsive to soil manipulations that disrupt soil physical structure (such as tillage), and the passive pool is the least likely to be influenced by changes in management practice.

<u>Expected evolution of the indicator</u>. C and N mineralization rates, as well as microbial biomass and soil respiration can evolve within a few hours or days and are extremely sensitive to changes in climate, land use and soil management. However, this sensitiveness does not affect with the same intensity the entire soil C pool, being the labile fraction much more responsive than the more recalcitrant parts (Conant et al., 2012) Therefore, the proportion of soil organic C belonging to different recalcitrance/lability classes is highly informative of carbon stability in soil and of soil potential for carbon sequestration. Early impacts of management on soil carbon dynamics and on soil capacity to supply nutrients to plants can be assessed based on changes in the proportion of total soil carbon that is labile.

SOM decomposition rates increase (and soil C stocks decline) when natural ecosystems are transformed to crops (Guo & Gifford, 2002) and, inversely, are expected to decrease with abandonment age. With increasing periods under herbaceous vegetation, both soil total organic C content and the amount of the labile organic fraction are expected to increase (Haynes, 2000). In the same sense, recalcitrance increases as plant cover ages and matures (Pregitzer & Euskirchen, 2004).

<u>Recommendations for the monitoring program</u>. It can take several decades after afforestation before effects on SOC pools can be observed in deep soil horizons (Shi et al., 2013), but effects of cultivation cessation or reforestation of bare soils on the labile fraction of the upper organic soil layers are measurable after 3 to 5 years. Measures of total soil organic C and of the size of the labile C pool should be included in the monitoring plans every 5 years. The proportion of labile C exhibits a large seasonal variability associated with changes in soil moisture, rainfall, temperature,

rhizodeposition and leaf fall (Haynes, 2005) and, therefore, sampling must always be made in the same period of the year in order to make measures comparable. The samples should be taken at the same depth, preferably in the upper 0-15 cm of the soil.
Analysis method. There are several methods to calculate the fractions of soil organic C belonging to the active, slow and stable pools. In this work, and depending on the soil type, we are applying two of them: (a) long-term soil incubations, and (b) organic matter digestion with increasingly aggressive acids.

Soil incubation

Long-term soil incubation under optimal conditions (a constant temperature of 25 ºC and about 50% of soil water holding capacity) is the cheapest method, although it can take many months in very organic soils. The method consists at letting a known quantity of soil to respire into a closed bottle and at measuring the CO_2 produced at increasing time intervals. In general terms, the rate of CO_2 production over time (e.g. CO_2-C g^{-1} day^{-1}) follows an exponential decay curve from which the size of the three C pools and their independent decomposition rates may be calculated as follows (Robertson & Paul, 2000):

$$\text{C Mineralization} = k_1 (C_1 e^{-k_1 t}) + k_2 (C_2 e^{-k_2 t})$$

where C_1 is the C content of the labile C pool, k_1 is the decomposition rate constant for the C_1 pool, C_2 is C content of the slow turnover pool, k_2 is the decomposition rate constant for the intermediate pool, and t is incubation time in days.

To calculate the size of the recalcitrant pool (C_3), an analysis of total organic carbon (TOC) is required. The recalcitrant pool can be then calculated as:
$C_3 = TOC - (C_1 + C_2)$

Soil acid hydrolysis

We are using a two-step H_2SO_4 acid hydrolysis procedure (Rovira & Vallejo, 2002, with little modifications) to determine the size of the soil labile C pool (composed of polysaccharides and cellulose) and of the recalcitrant C pool (composed of wax-derived long-chain aliphatic and aromatic components). Briefly, soil samples are first hydrolyzed with 2.5 M H_2SO_4 at 105 °C for 30 min. Subsequently, the remaining residue is hydrolyzed with 13 M H_2SO_4 and shaken overnight at room temperature. Then, distilled water is added to dilute the acid concentration to 1 M, and the sample is hydrolyzed at 105 °C for 3 h. The hydrolysate is regarded as labile pool. The remaining soil residue is rinsed twice with distilled water and dried at 60 °C. This fraction is considered the recalcitrant SOM pool. The C concentration in the labile and recalcitrant C pools are determined using a TOC analyzer.

Carbon sequestration in soil: physical protection

Definition and relevance of the indicator. Stabilization in soil aggregates is the principal mechanism for long-term sequestration of C onto SOM. An increase in SOM is generally associated with an increase in C found in macro-aggregates, and long-term carbon sequestration depends on its stabilization in soil micro-aggregates (Six et al., 2000). Soil aggregation promotes the physical protection of the stored C by decreasing C loss by erosion and by protecting it from mineralization.

Expected evolution of the indicator. Revegetation, soil restoration and soil conservation practices included in the NBSs are expected to increase the passive C pool and to improve soil structure. Hence, we expect increasing C incorporation into soil micro-aggregates.

Recommendations for the monitoring program. Carbon physical protection in soil aggregates should be evaluated every 5 years.

Analysis method. The soil samples are taken at 0-15 cm depth. Before analysis, the samples are air-dried and sieved at <5mm. We use the wet sieving method to separate the aggregates into three size classes: macro-aggregates (> 212 µm), meso-aggregates (53–212 µm) and micro-aggregates (20–53 µm) (Klute et al., 1996). For each size class, we determine TOC and calculate the proportion of physically protected C as the ratio between C in crushed samples and C in undisturbed samples.

2.2.2. d. Soil loss by water erosion

Definition and relevance of the indicator. Soil erosion can be defined as the accelerated removal of topsoil from the land surface through water, wind or tillage (FAO, 2015).

Deforestation, overgrazing and construction are among the most powerful erosive factors in mountains while, in agricultural zones, inappropriate practices cause critical soil losses and contribute to water pollution by sediments and associated chemicals (Grimm et al., 2001). The mean soil loss rate in the European Union erosion-prone lands (agricultural, forests and semi-natural lands) is about 2,46 t ha^{-1} yr^{-1}, resulting in a total soil loss of 970 Mt yr^{-1} (Panagos & Borrelli, 2017). Reported rates of soil formation by watering are within a range of approximately 0,3 to 1,45 t ha^{-1} yr^{-1} for European soils (Verheijen et al., 2009), which can be considered the maximum tolerable erosion rate to maintain a stable soil pool. Since the informed soil loss rates are higher by a factor of 1,7 compared to soil formation rates, erosion is a main concern for environmental management.

Water erosion is estimated to be the most extensive form of erosion occurring in Europe. In a given site, the extend of water erosion depends on several factors, including rainfall erosivity, land surface slope, soil vegetative cover, land management and soil erodibility that, in turn, is done by soil intrinsic properties such as texture and organic matter content. Silty soils are the most erodible of all soils, while organic matter protects soil against erosion. Among the factors explaining the intensity of soil erosion, plant cover and land use are considered the most important, exceeding by far the influence of rainfall intensity and slope gradient (García-Ruiz, 2010).

Expected evolution of the indicator. Since soil plant cover plays a key role in erosion control, increasing cover by revegetation is expected to result in decreasing erosion rates. In the agricultural areas, where a proportion of the cultivated land is proposed for conversion in non-cultivated and vegetated strips, the suppression of tillage and the development of a permanent soil cover will also reduce water erosion and improve the physical and chemical quality of the surface waters.

Recommendations for the monitoring program. Erosion taxes can be higher immediately after NBS application compared with their pre-operational values, due to soil disturbance by works and slow development of the protective plant cover. To correctly evaluate NBS effects on this parameter, erosion values should be registered previous to NBS implementation, immediately after application and then yearly during five years in the Massaciuccoli lake case and Santa Elena road cut. In this last case, a new evaluation 10 years after operation is advisable. In the case of the Capet forest, where soil and plant cover disturbance will be minimal during operations, erosion can be assessed every two years after NBS application.

Analysis method. Water erosion takes different forms of growing intensity and impact on soil loss: rain splash, sheet, rill, gully erosion and even landslides at the worst scenario. To estimate impacts of the proposed NBSs on soil erosion, several methods of direct measurement of modelling are proposed in this project depending on the study case. For the Santa Elena road cut ant the Capet forest cases, we are applying the RUSLE model. For the Massaciuccoli Lake case, we are applying an erosion model specifically designed to evaluate effects of vegetated filters on soil sediment exportation to surface waters from agricultural lands (VFSMOD-W: Vegetative Filter Strips Modelling System; Muñoz-Carpena et al., 1999). Finally, in the Massaciuccoli Lake, a real field measurement of sediment exportation by erosion micro-plots, as well as an analysis of the nutrient and agrochemical load in the runoff water is highly advisable before and after NBS application, although temporal and financial restrictions impede the application of this method by our research team. In this sense, preliminary studies have been conducted recently in the Massaciuccoli Lake agricultural area (Silvestri et al., 2016) that should be replicated in the specific farms where the implementation of vegetated filters is previewed. We will describe here, briefly the abovementioned erosion models we are applying.

The RUSLE model

To predict total soil loss due to sheet and rill erosion, the Universal Soil Loss Equation (USLE, Wischmeier & Smith, 1978) and its renewed version (RUSLE, Renard et al., 1991) are the most universally employed models.
In the USLE, total soil loss (A, in t ha^{-1} yr^{-1}) is calculated as follows:

$$A= R^* K * L^*S * CP$$

with R representing climate “erosivity” (or climate “aggressiveness”), K representing soil “erodibility” (or soil susceptibility to being eroded), L and S representing the topography of the watershed (slope length –L– and angle –S–), C representing plant cover and management (in particular, soil protection by plant cover) and P representing any soil protection practice implemented in the watershed.

Therefore, the effects on soil loss of any NBS leading to changes in plant cover, soil surface slope and/or terracing can be modelled by modifying the values of L, S, C and P. For arable lands, C depends on crop type and management (basically tillage and plant debris management). For non-arable lands, C values are available for different types of forests, shrubs and prairies (Panagos et al., 2015).

Different calculation methods and equations are available from literature, and tables containing R and K values have been calculated for different world regions (Benavidez et al., 2018). For our study cases, reliable data are available from the European Soil Data Centre Website (https://esdac.jrc.ec.europa.eu/content/cover-management-factor-c-factor-eu; https://esdac.jrc.ec.europa.eu/themes/rainfall-erosivity-europe).

The erosion base-line is being modelled currently by loading the RUSLE model with topographic (L and S) values obtained from the digital elevation model generated from the most recent aerial LIDAR (the Light Detection and Ranging remote sensing method used to examine the surface of the Earth). Plant cover values (C) were obtained from our field inventories supported by drone images in the two study cases of the Pyrenees; P values for the agricultural area of the Massacioccoli Lake are being provided by the landowners to our team through Dr. Nicola Sivestri (University of Pisa).

Vegetative Filter Strips Modelling System (VFSMS)

When rainfall surpasses the infiltration capacity of the terrain, runoff ensues. The resulting overland flow gives rise to erosion, which transports sediments downslope and away and causes a decrease in soil fertility (FAO 1993). Such soil loss can be determined experimentally from field plots, where plot dimensions, runoff flow and soil characteristics are selected according to the objectives of the study. Although results from such trials are most relevant, it is often the case that we need to perform many tests where one or some parameters are tuned repeatedly according to some pre-selected criteria. In this case, such multiple experimental testing may become cumbersome, or entirely impractical.

One of the solutions to limiting erosion and sediment transport due to runoff is the implementation of vegetative filter strips. Those vegetated strips are defined as "areas of vegetation designed to remove sediment and other pollutants from surface water runoff by filtration, deposition, infiltration, adsorption, absorption, decomposition, and volatilization" (Dillaha et al., 1989).

In addition to field experiments, total amount of soil loss for VFS solutions can be determined to high precision by numerical modelling. In particular, the Vegetative Filter Strip Modeling System (VFSMOD) (Muñoz-Carpena & Parsons, 2004) consists of a series of software modules that implement appropriate mathematical equations to model the physics of sediment and pollutant transport. They offer a numerical solution to the problem of removing suspended solids and pollutants by letting surface water runoff flow through a vegetated strip.

In the case of the Massaciuccoli Lake, the VFSMOD model is used to measure the effect of adding buffer strips on both sides of an irrigation channel to prevent sediments and eroded materials from leaving the fields.

Description of the indicator. Measurement of soil loss after a rain event is determined by VFSMOD as the amount of sediment that is retained by the vegetative filter strip (VFS), in Kg, relative to the amount of inflow sediment. Sediment retention is calculated by feeding the numerical software with the characteristics of selected storm events of varying intensity and duration. The user must also determine beforehand the set of soil parameters that best describe the study area. That area is divided into a source area, where the outflow of pollutants originates, and a vegetated strip, where flow is slowed down by vegetation, allowing sediment deposition to take place.

Modelling procedure: The VFSMOD software requires a series of inputs which describe:

1. Storm type, describing the amount of rain height falls per unit of time
2. Attributes of the upslope and the VFS area (e.g. slope, width and length)
3. Properties of the soil (e.g. porosity, Manning coefficients)
4. Characteristics of the vegetation in the VFS (e.g. stem separation and height, vegetation type).

Input datasets must be collected on site or derived from available sources. Slope, which to a great extent determines the volume of runoff that reaches the VFS, can be measured from elevation data available for the Massaciuccoli area (a detailed 1×1m digital elevation model (DEM) is available online at: http://www502.regione.toscana.it/geoscopio/ cartoteca.html).

Expected evolution of the indicator: Soil loss during rain events is expected to diminish thanks to the impact of the VFS on runoff. Assuming appropriate maintenance, the effect of the VFS should carry on in the near future. Nevertheless, runoff that is diverted sideways towards the small channels running along the study area will not flow through the VFS. Thus, the decrease in soil loss is probably far less than desired. To avoid that diversion, affected areas should be modified to force runoff water to flow solely through the VFS.

Recommendations for the monitoring program. Maintenance of the VFS is essential and must be carried out regularly and, especially, after rain events of any intensity. Appropriate maintenance work includes, among others:

- Replanting of vegetation in the VFS, if required
- Scrubbing and removal of unwanted vegetation that may hamper the optimum functioning of the VFS

- Carrying out level spreading work to keep uniform flow conditions through the VFS
- Repair of eroded or damaged areas
- Removal of sediment from VFS once a year, or whenever sediment load zone grows beyond optimal dimensions.

2.2.2. e. Soil erodibility: aggregate stability

Definition and relevance of the indicator. Soil aggregate stability is a key indicator of soil structure stability and soil physical degradation. In general, soil structure depends on the presence of stable aggregates composed of primary particles and binding agents (organics and inorganics), which are the basic units of soil structure. Stability of an aggregate is its ability to resist stresses such as tillage, swelling, and shrinking processes and fast wetting by rain and in general every mechanical or physical-chemical disturbs that cause aggregate disintegration. Structure is an important soil propriety that exerts direct influence in ecosystem processes such as supporting plant growth, animal life, soil organic carbon sequestration and water quality (Bronick & Lal, 2005). Favourable soil structure and soil aggregate stability are important factors that influence soil fertility, preserve soil productivity and decrease soil erodibility. Soil erosion is a key issue in mountain regions worldwide because mountain soils develop in a very sensitive environments subject to natural and anthropic disturbance. Moreover, these soils are generally shallow, and erosion represents a crucial problem affecting the landscape at different scale and is a serious challenge for land management and soil conservation.

Expected evolution of the indicator. Specifically, land use intensification and land degradation usually result in decline of soil structure and increasing soil erodibility (Bronick & Lal, 2005). Therefore, in the PHUSICOS study cases, the application of the proposed NBSs is expected to improve soil structure over time and, consequently, to increase aggregate stability.

Recommendations for the monitoring program. Analyze soil aggregate stability every 5 years.

Analysis method. Soil aggregate stability is measured from soil samples taken at 0-15 cm depth. Before analysis, the samples are air-dried, homogenized and sieved at <5mm. We use the wet sieving method to evaluate aggregate stability and separate aggregates into three size classes: macro-aggregates (> 212 µm), meso-aggregates (53–212 µm) and micro-aggregates (20–53 µm) (Klute et al., 1996). We calculate two indexes expressing soil aggregate stability: mean weighted diameter (MWD) and geometric mean diameter (GMD) (Le Bissonais, 1996) and, according to Shirazi & Boersma (1984), soil erodibility (K value).

2.2.2. f. Soil water holding capacity

Definition and relevance of the indicator. Soil Water Holding Capacity (WHC) is an important characteristic of terrestrial ecosystem as it provides a simple measure of soil ability to provide water for plant growth. WHC is a hydraulic propriety of the soil and is the amount of water available for plants that soil can hold against the force of gravity. WHC is defined by the amount of water held by soil between field capacity and permanent wilting point.

Expected evolution of the indicator. WHC is governed by soil texture and soil organic matter content. The first depends strongly and almost exclusively on parent material; on the contrary, SOM is expected to increase due to the application of NBSs that promote soil enrichment.
Recommendations for the monitoring program. Measure WHC every 5 years.

Analysis method. WHC is measured by saturating the soil by placing it in tubes (7cm Ø and 8 cm height) with a groove in the bottom (50µm pore) to avoid the loss of small soil particles, and by putting the tubes to soak in water for 24 hours. Subsequently, the containers are placed on a support inside a closed box lo let the excess of water drain by gravity while preventing evaporation for 24 h. The tubes are then weighed and dried at 105 ºC for 24 hours. The WHC is calculated as the difference between the dry weight and the weight of the soil let to drain 24 hours.

2.2.2. g. Soil nutrients, texture and electrical conductivity

Definition and relevance of the indicator. Available nutrients, well-adjusted texture (appropriated proportion of sand, clay and silt), correct physical structure and low or no salinity are required conditions for soil fertility and plant growth. Soil fertility is a requirement of any kind of vegetation but is especially important in the case of agricultural landscapes, where plant production is the main environmental service required of soil. In any terrestrial environment, identifying limiting nutrients is very important, because alterations in their supply have the capacity to transform the structure and functioning of ecosystems (Vitousek et al., 2010).

Fertile soils contain some organic matter (that improves soil structure, soil water retention and also nutrient slow provision and retention) and all the major nutrients required for plant production (e.g. nitrogen, phosphorus, and potassium), as well as other nutrients needed in smaller quantities (e.g., calcium, magnesium, sulfur, iron, zinc, copper, boron, molybdenum, nickel). Nutrients are present in soil in different chemical forms, some of which are insoluble and unavailable to plants. Soil acidity is a paramount factor in determining nutrient availability. For example, calcium, potassium and magnesium are available in basic soils, while iron, manganese, zinc or copper are more available in acidic soils. Phosphorous, a very limiting plant nutrient in Mediterranean environments, is available to plants at intermediate values of soil acidity. Acidity is measured through "pH" with pH<6 corresponding to acidic soils, pH>7 corresponding to basic soils, and 6<pH<7 corresponding to neutral soils (Sparks, 2003).

Another important soil quality parameter is salinity that can be evaluated by measuring soil electrical conductivity and/or sodium content. Salinity is a common problem in irrigated agricultural lands under arid climate conditions, but also in areas with shallow water tables belonging to aquifers affected by seawater intrusion. Tolerance to salinity varies with crop type. Corn and sunflower are negatively affected by conductivity levels above 1,7 dS m^{-1}; soy and wheat are more tolerant, with visible negative effects on plant productivity starting at 5 and 6 dS.m^{-1} respectively (http://agrosal.ivia.es/).

Expected evolution of the indicator and recommendations for the monitoring program. Determining the status of the main soil nutrients is important after any intervention expected to cause dramatic changes in soil conditions and, very particularly, when the operations include topsoil importation or creation of new soils (technosoils) from mixtures of sterile mineral substrates and organic amendments. These are the cases of the remodelling of the Sta. Elena road cut and of the creation of agricultural areas at both sides of the Bastan riverbed. In these cases, the analysis of soil available nutrients and texture is required immediately after soil restoration to guarantee an appropriate substrate for vegetation and to alert about deficiencies that might require correction. No further analyses are recommended overtime except in case of symptoms of improper development of the vegetation. In the case of the vegetation strips around the agricultural plots of the Massaciuccoli Lake, a soil nutrient analysis should be performed before grass sowing to be sure that the soil condition is favourable to the chosen species. Further analyses can be required in case plant establishment and growth is not satisfactory.

Analysis method. Nutrient availability, electrical conductivity and texture make part of the determination of soil fertility and are assessed by standard analytical methods in agricultural labs at reasonable prices.

2.2.2. h. Soil functional biodiversity

Definition and relevance of the indicators. Soil harbours a large part of the world's biodiversity. By far the most abundant group of organisms are the soil microbes (e.g., viruses, bacteria, archaea and fungi) that, together with soil invertebrates (mainly protozoa, nematodes, mites, springtails, enchytraeids and earthworms), underlie crucial soil ecosystem processes, such as carbon sequestration, water cycle regulation, nutrient cycling, plant diversity regulation, decontamination and bioremediation, pest control or plant and human health (Turbé et al., 2010). Soil biodiversity evaluation is particularly important to estimate the ability of an ecosystem to respond to changing environmental conditions and to assess its resilience and sustainability.

The abundance and variety of belowground organisms is overwhelming, and often very difficult to handle even by experts. Bacteria and archaea amount to 4 to 10 x 10^9 genome equivalents per cm^3 of soil, and fungi to 200-235 OTUs (operational taxonomic units) per gram of soil. One m^2 of soil shelters 12.000 to 311.000 enchytraeids, 1 to 5 x 10^4 collembolans, and to 1 to 10 x10^4 oribatid mites (Bardgett & Van Der Putten, 2014).

A practical way of reducing this complexity to handy levels is to substitute taxonomic diversity by functional diversity, i.e. by the diversity of guilds of organisms that share similar characteristics, realize the same functions and show similar metabolic or behavioural responses to important environmental factors (such as temperature or water availability). In fact, it has been argued that it is diversity at the functional level rather than at the taxonomic level that is important for the long-term stability of an ecosystem (Walker, 1992).

In PHUSICOS, we are approaching soil functional diversity through three complementary perspectives: (a) soil trophic webs, (b) soil microbial functional gene diversity, and (c) soil microbial community level physiological profiling, addressed to the characterization and classification of heterotrophic microbial communities based on sole carbon source utilization patterns (Lehman et al., 1995).

Soil food webs and derived environmental services: carbon and nitrogen mineralization and ecosystem stability

Definition and relevance of the indicators. Trophic webs depict food relationships between different groups of the soil biota (basically, who eats whom and how much each one eats of the other) and, therefore, the forces predators exert on their prey and vice versa (Moore et al., 1988). In their simplest form, food webs picture links between feeding guilds (trophic species) by drawing arrows between prey and predator (Scheu, 2002).

A key advantage of this ordination of soil biodiversity is that, once the biomass of each trophic group (from field sampling and further classification of microbes and invertebrates) and their chemical (carbon to nitrogen ratio) and metabolic characteristics (feeding rate, assimilation efficiency, assimilation efficiency; production efficiency; specific natural death rate) are known, the flux of energy and matter through the system can be calculated. Soil food webs must include the following trophic groups that are almost always present in soils: bacteria, fungi, protists (flagellates, amoeba and ciliates), nematodes (plant feeders, bacterial feeders, fungal feeders, predatory and omnivores), springtails, detritivore oribatid mites and predatory mites. Any other less ubiquitous invertebrate group found in a relevant percentage of the samples must also be included.

Classical and very important outputs of the soil food web models are carbon and nitrogen mineralization rates and CO_2 emissions to the atmosphere (De Ruiter et al., 1993) that we use as biological indicators of soil quality. Another important indicator that can be calculated from food web schemes is stability. Food web stability can be described as a measure of the likelihood of the persistence of the interacting soil species or functional groups following disturbances or environmental impacts. Stability guarantees enduring diversity and preserving the provision of soil environmental services in front of environmental fluctuations, which is primeval under current climate uncertainty (Schwarz et al., 2017).

The debate about which metrics of a food web determine ecosystem stability is long-lasting (see Dune, 2006). At the beginning of the twentieth century, stability was supposed to be correlated with species diversity, based on the observation that low diversity ecosystems (as recently restored or agricultural environments) are more prone to destructive oscillations than richer ones, and more vulnerable to invasions. This supposition is no longer relevant, and stability is now most often justified based on the relative importance of the bacterial food channels that exhibit, on average, more abundant and weaker interactions among groups (Rooney et al., 2006).

Some of the groups used to build up the trophic web models, as well as the relative importance of their biomass may also be independently used as indicators of soil quality, maturity and post-disturbance recovery. Good ecosystem response indicators can be extracted from nematodes (Neher, 2001), protists (Foissner, 1999) or fungal to bacterial biomass ratios (Bailey et al., 2002).

Expected evolution of the indicators. Several ecosystem indicators can be derived from the soil food web model, of which we will only mention here the most evident. The fungal to bacterial biomass ratio is expected to increase as soil quality improves or soil matures after restoration/recreation (Bailey et al., 2002). The importance of the "bacterial channel" in terms of biomass and energy and matter flows is expected to decline compared to the "fungal channel" as soil quality rises, and the same can be said for soil CO_2 emissions, which means that soil metabolism becomes increasingly conservative (de Vries et al., 2013). Following this decline, the stability of the soil community and delivered ecosystem services are expected to increase with time after NBSs' application.

Recommendations for the monitoring program. Unfortunately, soil trophic web study requires expertise for identification and computation of the different groups and further modelling. Therefore, monitoring the post-operation evolution of the soil food-web is very desirable but not feasible unless the monitoring plan includes funds for contracting expert assistance. Over the course of this project, we expect to find reliable relationships between soil food web complex indicators and other biological indexes of soil quality easier to calculate. The evolution of these biological indicators should be ideally monitored every 5 years. Belowground populations fluctuate seasonally, with the highest size and activity occurring during the plant growing period. Therefore, the sampling campaigns should be conducted in April-May or September-October in the two study cases of the Pyrenees (preferably in the fall to get results comparable with those of the base-line), in June (after snowmelt) in the Norwegian case, and in September-October in the Massaciuccoli Lake agricultural area. In this last case, the sampling dates must be adapted to the agricultural calendar, to take advantage of the short resting period before tillage.

Analysis method. Bacterial and fungal biomasses are calculated from direct count of slides under epifluorescence microscope (Bloem, 1995). Protist abundance (sorted into ciliates, amoebas and flagellates) is estimated by the most probable number method (Darbyshire et al., 1974). We extract nematodes from 40 g soil samples with Baermann funnels for three days, and micro-arthropods from the whole soil cores (5cm Ø and 15 cm depth) in Tullgren funnels for 7 days, and sort them into trophic groups (following Moore et al., 1988) under classic (for microarthropods) or inverted (for nematodes) optical microscopes. All individuals included in a given functional group are attributed the same individual biomass, metabolic rate and feeding preferences based on literature. Biomass-C density is calculated then for each group by multiplying its abundance (in individuals per m^{-2} in the top 15 cm of the soil) by half the individual body weight attributed to the group, since we assume that 50% of the dry weight of the soil living biomass is made of carbon. At the time of writing, all samples from the two Pyrenees cases and the Massaciuccoli Lake case have been processed and the food web model will be loaded soon for energy fluxes, carbon and nitrogen mineralization and stability simulation. To do so, we are now applying the food web model described in depth in Moore & de Ruiter (2012). The suitability of this model to predict real N and C mineralization rates has been tested by comparing values for *k* obtained by simulation with those obtained from lab incubation under controlled conditions (Schröter et al., 2003).

2.2.2. j. (b). Microbial taxonomic and functional diversity

Definition and relevance of the indicator. Soil microbial communities play a pivotal role in terrestrial ecosystems by reintegrating the essential nutrients into biogeochemical cycles, and by regulating plant growth and the quality of the atmosphere and hydrosphere. Microbial functional diversity can be defined as 'the sum of the ecological process, and /or the capacity to use different substrates developed by microorganisms of a community' (Nannipieri et al., 2003; Campbell et al., 2003)).The diversity of functions performed by organisms within ecosystems has been recognized as the missing link between biodiversity patterns and ecosystem functions. There is an increasing recognition that patterns of functional diversity may provide a more powerful test of theory than taxonomic richness.

Metagenomics analysis of soil provides a powerful tool for studying its functional capacities. Among all available metagenomics techniques, "Shotgun Metagenome Sequencing" is able to reveal taxonomic profiling (diversity and abundance), as well as functional attributes of soil microbial communities. Functional gene analysis is included in the list of powerful indicators aimed to monitor soil biodiversity and ecosystem function across Europe (Griffits et al., 2016).

Recommendations for the monitoring program. Taxonomic and functional diversity of soil microbial communities are useful variables for monitoring effects of management on soil conservation. Recommendation for a monitoring program are the same as those described in section *2.2.2. h (a)*.

Expected evolution of the indicator. We expect that the genetic and functional diversity of the soil microbial community and delivered ecosystem services increase with time after NBSs' application.

Analysis method. Soil is sampled at 0-15 cm depth and stored at -20 ºC. DNA is extracted from soil with the Soil Microbe Microprep Kit (Zymo, USA). Shotgun metagenomics are conducted following the Illumina Paired-End Prep kit protocol. At the time of writing, the soil samples of the two Pyrenees cases and the Massaciuccoli

Lake are being analyzed while we progress in the description of the final bioinformatics analyses.

Soil microbial community level physiological profiling (CLPP)

Definition and relevance of the indicator. Community-level physiological profiles of the soil microbial community can be assessed by measuring microbial utilization of a wide range of carbon sources. MicroResp™ is an appropriate, rapid and sensitive method for determination of soil microbial CLPPs. The MicroResp™ assay is included in the list of most powerful indicators recommended to monitor soil biodiversity and ecosystem functions across Europe (Griffiths et al., 2016).

Recommendations for the monitoring program. Repeat the analysis every 5 years following the recommendations consigned in section *2.2.2. h.*

Expected evolution of the indicator. We posit that the ability of the soil microbial community to metabolize increasingly recalcitrant chemicals will increase with time and ecosystem maturation after the application of the proposed NBSs.

Analysis method. Microresp™ assay is applied to soil samples taken at 0-15 cm depth, sieved at <2mm and stored at 4 ºC. Soils are adjusted to 40% of their WHC and loaded into 1,2 ml deep-well plate (ca. 0,35 g soil per well). Subsequently, the samples are stored for 5 days at 25 ºC within a CO_2 trap, as recommended by the fabricants. The physiological profiles are determined using 15 different sourced of carbon: two simple sugars (D-glucose, D-fructose); one disaccharide (sucrose); one polysaccharide (cellulose); three amino acids (γ-aminobutyric acid, L-proline, L-arginine); three carboxylic acids (α-ketoglutarate, citric acid, L-malic acid); one aromatic carboxylic acid (protocatechuic acid); one polymer (a-cyclodextrin); one chiral (mannitol), one polyol (glycerol) and one sugar alcohol (meso-erythriol).

2.2.3 Vegetation indicators

2.2.3. a. Aboveground tree carbon stock

Definition and relevance of the indicator. The aboveground tree carbon (C) stock is the amount of C stored in the aboveground of living trees expressed in tonnes of C per hectare.

The stock of C in forest trees is a consequence of the balance between its increase as a result of tree growth and its decrease by tree exploitation and mortality (Vayreda et al., 2012). If tree growth surpasses the losses, the result is C accumulation; on the contrary, if losses exceed growth, the stock of C decreases. If forest management is designed to obtain energy, the whole C stock is immediately released into the atmosphere as CO_2. On the contrary, if forest management is oriented to produce wood for long-lasting products, such as furniture, the stored C remains sequestered throughout the product life. On the other hand, the C contained in dead trees is gradually released into the atmosphere as a result of their decomposition at a rate that depends on multiple factors of which temperature, humidity, the position of the tree (standing or lying down) and its size are the most determining (Harmon 2009).

Expected evolution of the indicator. In the absence of high intensity disturbances (unsustainable exploitation, snow slides, windstorms, wildfire...) it is expected that the C stock of the aboveground biomass will increase over time until final stabilization.

Recommendations for the monitoring program. Follow the evolution of aboveground tree C stock every 5 years.

Sampling method. The C stock is obtained from measuring the size of all trees (diameter at breast height, DBH $\geq$ 7.5 cm and height) of any species present in circular plots of fixed radius. With this information, the biomass of each tree is calculated by using biomass equation at the species level, that relate tree DBH and height and their aboveground biomass (Gracia et al., 2004; Montero et al., 2005). Biomass is then converted to C by multiplying by 0,5. Finally, the sum of C of all trees is scaled up to hectare in relation to the sampling area.

2.2.3. b. Plant species diversity: Shannon Index

Definition and relevance of the indicator. The Shannon Index (H') is a measure of diversity and is a function of the number of tree species and their proportion (Shannon, 1949). This indicator is dimensionless.

As a measure of tree species diversity, the Shannon index is calculated as:

$$H' = \Sigma\, p_i \cdot \ln (p_i)$$

where, for each species observed in a plot, p_i is the proportion of total the plot basal area contributed by trees of the i^{th} species. For this project, p_i is based on the basal area to avoid problems caused by large numbers of very small trees (Staudhammer & LeMay, 2001). The Shannon index is 0 when all trees belong to the same species, increases as more species are measured, and is maximized for a given number of species when the proportions are equal (Mc Roberts et al., 2012).

Expected evolution of the indicator. In the short term, the probability that a new tree species appears is reduced. However, if at time 0 (t_0) there is more than one species in the sampling plot, the proportion of each one is likely to change over time because the dynamics (harvest, growth, mortality and, recruitment rate) of each species may be different.

Recommendations for the monitoring program. Follow the evolution of species diversity every 5 years.

Sampling method. The sampling method consists of measuring the DBH ($\geq$ 7,5 cm) of all trees of any species into circular plots of fixed radius. With this information, the basal area per species of each tree is calculated according to its DBH. The proportion of each species is obtained as the ratio of the basal area of the species to the total basal area.

2.2.3. c. Invasive species

Definition and relevance of the indicator. The proportion of invasive tree species (non-native) is an indicator of the degree of ecosystem disturbance. A species is considered invasive when it rapidly colonizes and occupies a space by altering ecological integrity and ecosystem services (Charles & Dukes, 2008; Pejchar & Mooney, 2009) by hindering the regeneration, establishment and growth of native species. In addition, once established, even in small proportions, eradication is almost always very difficult. Moreover, the presence of invasive species disrupts the fundamental structure and function of the ecosystem food webs, and consequently reduces native biodiversity (Ehrenfeld, 2010). In addition, considerably negative impacts for socioeconomic and human welfare have been reported (Pimentel et al., 2005; Vilà et al., 2010, Andreu & Vilà, 2011).

The presence of invasive tree species is usually related to altered habitats that leave open spaces allowing rapid colonization. Riparian habitats tend to be very auspicious spaces especially after the alteration caused by large avenues of water. Another factor that determines their establishment is the proximity to urban areas or roads (González-Moreno et al., 2012).

Expected evolution of the indicator. In the short term, the likelihood of establishment of invasive species will depend primarily on the proximity of propagules and the presence of high intensity disturbances even if they are open spaces at a very local scale.

Recommendations for the monitoring program. In order to detect straight away the presence of invasive species, it is highly recommended to carry out an exhaustive follow-up at least every 5 years making exhaustive paths of all the monitored area.

Sampling method. The sampling method consists of detecting the presence of invasive tree species at any development stage, from seedlings to adult trees. For each development stage the percentage of coverage and the average height should be registered.

2.2.3. d. Total vegetation cover

Definition and relevance of the indicator. The indicator measures the proportion of soil covered by vegetation (trees, shrubs, herbaceous vegetation or mosses). A greater vegetation cover means a lower proportion of bare soil and, consequently, a lower erosion risk. If vegetation is absent soil is more exposed to erosive agents.
Other key factors that determine soil erodibility are topography (the stepper the terrain the higher the erodibility) and the intrinsic characteristics of each soil type (texture,

structure, etc.). Finally, the erosion risk will depend on the precipitation regime (quantity and intensity) that will determine the runoff (Panagos et al., 2015; Moran-Ordoñez et al. Submitted).

Expected evolution of the indicator. In the absence of high intensity disturbances (unsustainable exploitation, snow slides, windstorms, wildfire...) it is expected that the vegetation cover increases or at least remains stable over time until reaching values close to 100%.

Recommendations for the monitoring program. Follow the evolution of total vegetation cover every 5 years.

Analysis method. The method of sampling is to estimate the percentage of any type of vegetation through its projection on the ground, or 100 minus the percent of soil not covered by vegetation. The value must be between 0 and 100 with an accuracy of 5%.

2.2.3. e. Non-woody plant cover

Definition and relevance of the indicator. As "Total vegetation cover", but considering only herbaceous vegetation (grasses), ferns, mosses and liverworts.
Following the considerations of the previous indicator, in relation to erodibility, it is important not only that vegetation cover is high but also that the height of the vegetation is small to reduce the erosive effect of the raindrop impact on the soil. Greater coverage of short vegetation means higher protection of soil against erosion.

Expected evolution of the indicator. In the absence of high intensity disturbances (unsustainable exploitation, snow slides, windstorms, wildfire...) and without woody vegetation (trees or shrubs) it is expected that the non-woody vegetation cover increases or at least remains constant over time. If the canopy tree increases, the shrub and grass cover tend to decrease due to lack of sunlight.

Recommendations for the monitoring program. Follow the evolution of total non-woody plant cover every 5 years.

Analysis method. Field visits to estimate the percentage of any type of non-woody vegetation and its projection on the ground. The value must be between 0 and 100 with an accuracy of 5%.

2.2.3. f. Plant Moisture Index

Definition and relevance of the indicator. Is the moisture content of fine fuel (live and dead fuel, less than 6 mm, with high surface-area-to-volume ratio, that dries readily and is rapidly consumed by fire when dry) of all woody species. Moisture content of fine fuels is known to be an important factor in flammability and fire behaviour (Dias et al., 2010).

Low fuel moisture content has a significant impact upon fire behaviour, affecting its ignition, spread, and intensity; with high winds, it can lead to extreme fire behaviour. High proportion of fine fuel together with low fuel moisture contents and high volatile oil contents will contribute to rapid fire spread and high fire line intensities, making initial attack and suppression difficult (Anderson, 1982).

The plant moisture index varies throughout the year because it is a function of the time elapsed without precipitation, relative humidity, air temperature, soil type, etc. In Mediterranean climate, the lowest values typically occur during the summer. However, not all species respond in the same way. Some species are able to maintain a high and relatively constant moisture content even under extreme conditions by controlling water losses by regulating stomata (e.g. *Pinus halepensis* and *Quercus coccifera*), while other species have a lower capacity (e.g., some species of the *Cistus* genus, *Rosmarinus officinalis*, etc.) (Dias et al., 2010; Martin St-Paul et al., 2018).

<u>Expected evolution of the indicator</u>. This indicator has a clear seasonal periodicity. In Mediterranean climate it reaches minimum values in summer when the highest temperatures and the longest period without precipitation coincide.

<u>Recommendations for the monitoring program</u>. Since each species responds differently, it is essential to know the minimum value of water content. If there is no bibliographic information available for a specific species, it should be obtained empirically by collecting samples of leaves and branches of less than 6 mm at different times of the year.

<u>Analysis and sampling methods</u>. Composite samples (50 to 75 g) are obtained from sets of branches with leaves smaller than 6 mm. The fresh sample is placed in an airtight container that prevents significant water losses during transport to the laboratory. Once at the laboratory, sample is weighed fresh, oven dried at 60 °C during 24 h and weighed dry. Finally, the water content of each plant (in %) is determined as:

$$PMI = \frac{fresh\ weight - dry\ weight}{dry\ weight}$$

2.2.3. g. Plant Flammability Index

<u>Definition and relevance of the indicator</u>. Flammability is the ability of a fuel to ignite after having been submitted to caloric energy (Elvira & Hernando, 1989; Valette, 1990). The fuel flammability classification is based on the classic definitions of Anderson (1970) & Martin (1994). The ignitability is measured as the time that a flame takes to appear in a sustained way (time-to-ignition); the sustainability of combustion is measured through the average effective heat of combustion and the total heat release (Madrigal et al 2009).

Flammability is characterized with a laboratory equipment called "calorimetric cone" that analyses both the combustion chemistry and the processes conducted by the transport of gases, which in the case of forest fuels may be more important than the chemical phase, since it depends on the structure, surface-volume ratio, bulk density, and fuel packing, among other variables (Madrigal et al., 2009). The knowledge and characterization of combustion from the point of view of gas transport is essential to extend conclusions on a real scale, where in most cases the fuel structure determines the flammability.

Expected evolution of the indicator. This indicator shows a clear seasonal pattern. In Mediterranean climate it reaches its maximum value in summer, when the highest temperatures and the longest dry period coincide.

Recommendations for the monitoring program. Since each species has a different flammability value, it is essential to get this value from literature. When there is no bibliographic information available for a specific species, it must be classified by similarity (in terms of chemical composition and structure) with other species of known flammability value.

Sampling method. The plant flammability index is the relative importance of each tree or shrub species previously classified by its specific flammability value at the worst time of the year (August in Mediterranean climate) according to 5 categories:

1. Very low flammability
2. Low flammability
3. Moderate flammability
4. High flammability
5. Very high flammability

2.2.4 Green infrastructure Indicators: the landscape connectivity

Definition and relevance of the indicator. A key problem in biodiversity conservation is the radical change in landscape pattern induced by anthropogenic activities that result, in turn, in strong alteration of landscape functions. Particularly, human activity leads to habitat loss and fragmentation, affecting key functional properties like landscape connectivity (Taylor et al., 1993; Fischer & Lindenmayer, 2006). For many wild species living in human-transformed landscapes, local extinctions of fragmented populations are common, and recolonization is critical for regional survival. Maintaining a non-negative dynamic in these metapopulations thus depends on a certain degree of connection between habitat patches (Fahrig & Merriam, 1994).

2.2.4. a. The Hanski's Index

Definition and relevance of the indicator. NBS should help to improve regional connectivity to ensure the conservation of biodiversity in human-transformed landscapes. However, assessing connectivity and its change over time under the deployment of NBS is not an easy task, as connectivity depends on both landscape spatial pattern and species mobility and ecology (particularly on tolerance to non-natural habitats) of the concerned organisms. Indeed, two main types of connectivity can be defined: i) structural connectivity which strictly describes the physical relationships between habitat patches such as inter-patch distances based on Euclidean units, and ii) functional connectivity which attempts to include the organism's behavioural response to both the landscape structure and the landscape matrix (Tischendorf & Fahrig, 2000; Taylor et al., 2006). As the solution is not easy, a myriad of connectivity metrics has been proposed for both types (Kindlmann & Bural, 2008), among which Hanski's connectivity index is one of the most frequently used.

Expected evolution of the indicator. With the application of NBS, the expected overall evolution of the indictor is increasing. However, values for some habitat types (e.g. non-woody ones) might decrease in the long term as succession to woody habitats progresses.

Recommendations for the monitoring program. As it strongly depends on the development of restored vegetation stands, it is recommended to follow the evolution of landscape connectivity every 5-10 years. It is also recommended to monitor both the overall landscape connectivity and that of its main habitat types (e.g. woody and non-woody habitats). Landscape connectivity is simply the average of connectivity maps obtained by these habitats.

Analysis method. The original Hanski's index is formulated as:

$$I_i = \Sigma_j \, e^{(-\alpha d_{ij})} . \, S_j$$

where:

- I_i is the Hanski's index for each habitat patch *i* in the landscape
- d_{ij} is the distance between a given patch (i) and any other patch in the system (j)
- S_j is the (other) patch area
- α is the parameter defining the dispersal kernel, reflecting the probability that individuals reach a certain distance. It is needed to scale the range at which connectivity happens (e.g. 1 km distance may not cause any effect on birds, but a serious isolation on snails). In the case of the negative exponential function, the most used kernel function, α can be approximated to the inverse of the average dispersal distance. An average kernel of 1-2 km is frequently used.

Thus, the index is calculated for each habitat patch and can be expressed in a spatially explicit way, using an appropriate GIS layer (e.g. a vectorial habitat map). Yet, this classical, patch-based calculation might be optimized through a pixel-based approach, in which the index is calculated for a set of points regularly placed across the landscape (e.g. every 100 m) and patches are substituted by pixels (then, S_j is constant and corresponds to the pixel area). This approach is then based on a raster representation of the landscape (e.g. a raster habitat map) and is especially adequate when the range of habitat patch sizes is especially large (e.g. when small habitat patches and large habitat mainland coexist in the same landscape, which is especially common).

On the other hand, connectivity should be assessed on the organism's movement ability through a landscape to be ecologically meaningful (Tischendorf & Fahrig, 2000). Then, the classical approach should be improved by assessing functional connectivity, through changing Euclidean distance *d* by a cost distance δ, that assumes a displacement cost of the organisms of specific habitats through the landscape units (i.e. land-cover or habitat categories). Cost distance δ corresponds to the least accumulative cost distance for each cell to the nearest source over a cost surface on the study area and it is performed using specific GIS tools (e.g. *costdistance* in ArcGIS o QGIS). In practice, cost surface is calculated based on a set of impedance values assigned to the categories belonging to either a land-cover or habitat map. We propose the following impedance values for woody and non-woody habitats in the specific case of PHUSICOS:

Table 3. Impedance values between the modelled and the rest of habitat types

	Woody	Non-woody
Woody habitats (forests and scrublands)	1	4
Non-woody (grasslands and rock outcrops)	4	1
Non-restored (bare soil, mining areas)	10	5
Urban	50	50

Please note that species of non-woody habitats are assumed to be more tolerant to non-restored areas than those of woody habitats.

Still, woody and non-woody habitats are not completely disjoint, as some species of one of these habitat types can survive or even reasonably live in the other. Thus, woody habitats can somewhat contribute to the connectivity of non-woody ones, and *vice versa*, yet this contribution is not equal to patches or pixels of the same habitat type. This can be assessed using an additional term, namely habitat affinity to a given habitat *i*, A_i, ranging from 0 (totally disjoint) to 1 (totally affine). We propose using the inverse of impedance as affinity values and that only woody and non-woody habitats contribute to connectivity (the rest of habitat types do not contribute to connectivity, only to cost distance).

Table 4. Affinity values between the modelled and the rest of habitat types

	Woody	Non-woody
Woody habitats (forests and scrublands)	1	0.25
Non-woody (grasslands and rock outcrops)	0.25	1
Non-restored (bare soil, mining areas)	0	0
Urban	0	0

The final formula of Hanski's index for each sampling point *i* and habitat type *k* results as:

$$I_{ik} = \Sigma_j\, e^{(-\alpha\delta_{ij})}.\ A_k S_j$$

Where S_j are all pixels within the kernel α, Ak corresponds to their affinity value, and δ_{ij} is the cost distance of these pixel to the sampling point. Using GIS tools, it is easy to build up a script for calculating this value per habitat type (woody and non-woody habitats) in a set of sampling points regularly placed in the study area. Then, a continuous connectivity map can be achieved per habitat type using interpolation methods. Overall connectivity will correspond to the average map of those from particular habitat types.

3 Demonstrator cases: Problems and NBSs

3.1 The case of the Forêt de Capet (Barèges, France)

3.1.1 The problem

Barèges (Hautes-Pyrénées, 42º 53’47.4”N; 0º 3’ 48.05”E, 1250 m.a.s.l.) is situated in the Bastan River Valley, at the foot of the Capet mountain (2328 m.a.s.l.) (Fig.1). In 2016, the stable population included 170 people distributed in 86 households. Besides, 922 holiday homes are registered (INSEE, 2019) which gives an indication of the touristic interest and high frequentation of this town, associated to the sky resorts of the Grand Tourmalet area.

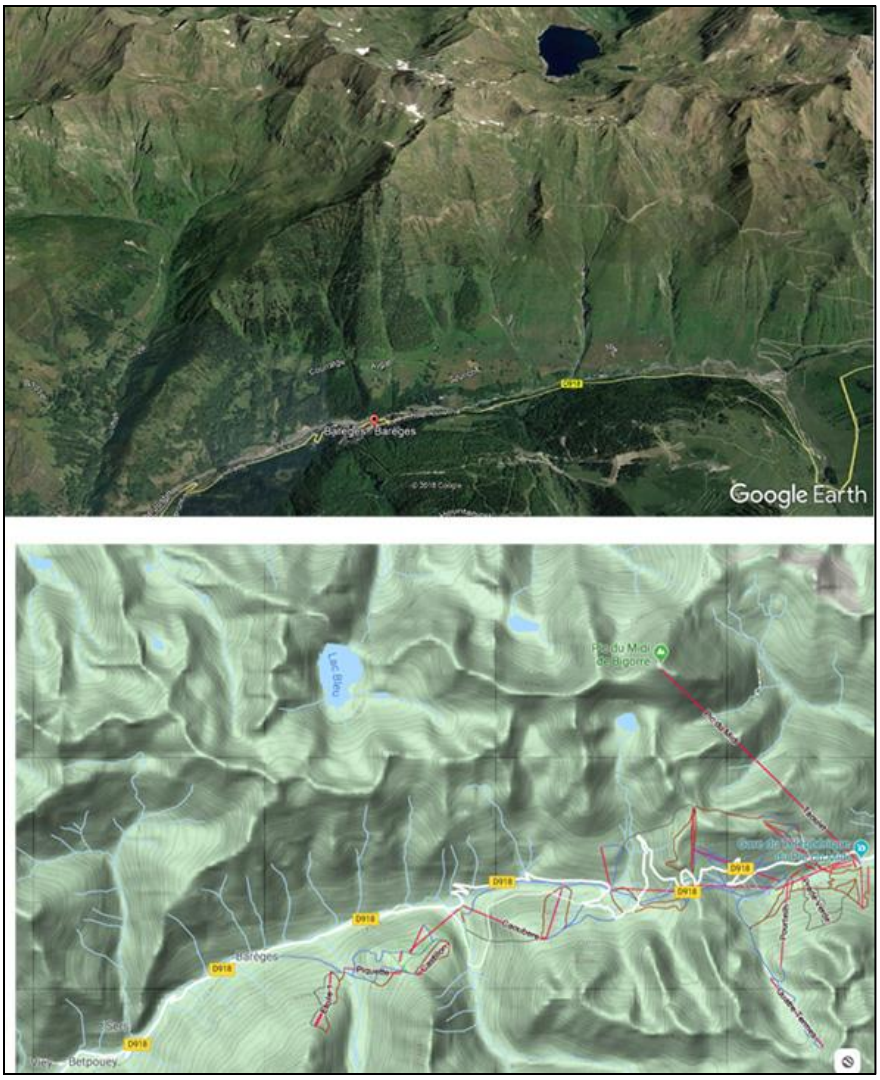

Figure 1. The Barèges area: landscape and topography

The town has been historically threatened by geological, hydrological and hydrogeological risks, including catastrophic flooding of the Bastan River and repeated and destructive snow avalanches that are being reported since 1644 (Lanusse et al., 1988).

The most threatening avalanches originate in the Midaou and Theil avalanche corridors (Fig. 2) that are being managed for risk mitigation since the second half of the XIXth century.

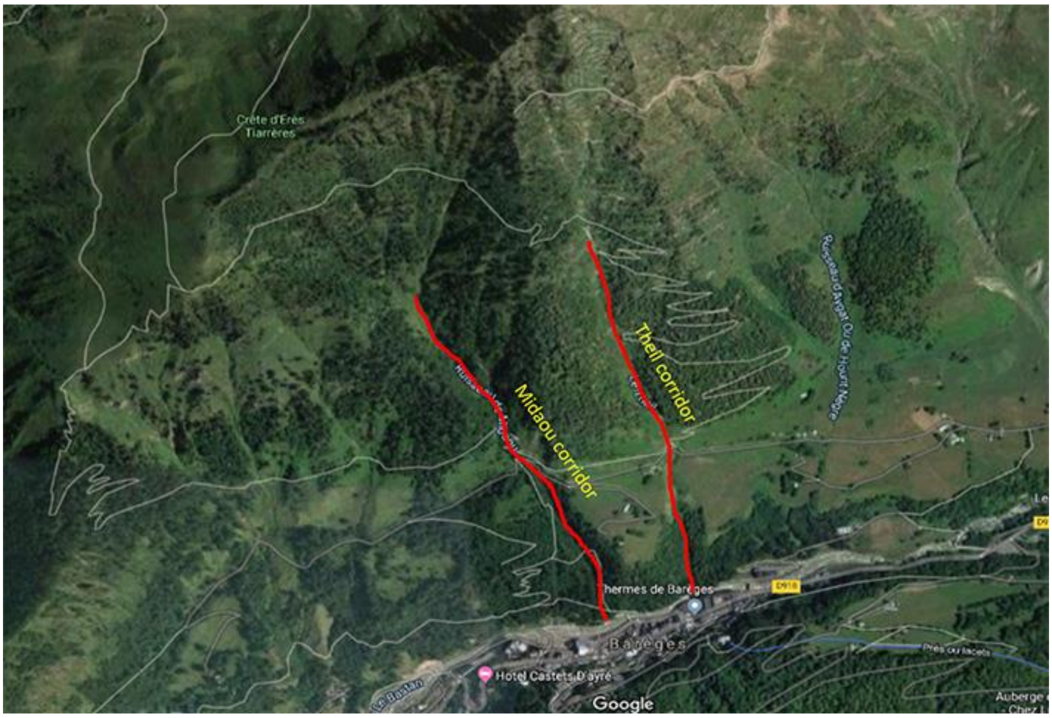

Figure 2. The Miadou and Theil avalanche corridors above Barèges

The Capet Forest, the public national forest that occupies 147 ha in the 1930-2120 m.a.s.l. fringe above Barèges, was designed as a protective forest by Napoleon III in 1860 which prompted and active reforestation of this area with coniferous trees during the 1880-1920 period (Lanusse et al., 1988). The top sector of the slopes was planted with native *Pinus uncinata* (mountain pine), while mixed forests of *Picea abies* (silver fir) and *Larix decidua* (European larch) were introduced in the lowest parts. *L. decidua* seeds were directly spread on the snow, since these trees require bare soil for recruitment and early establishment. Unfortunately, this property makes this species of very limited use for avalanche prevention.

To reinforce the anti-avalanche protection, dry stone walls were introduced in 1892 and, from then on, the defence system has been significantly improved and densified. Currently, together with the former stone walls, a dense network of cast-iron snow rakes is observable in the mountain slope, particularly concentrated in the area of the Thiel corridor (Fig. 3). About 900 protective structures (5232 lineal meters) are currently maintained by the ONF/RTM staff (Anonymous, 2011). Notwithstanding the deployment of protective measures, the avalanches continue to cause damages, as was the case in the winter of 2013 (Fig. 4).

Figure 3. Anti-avalanche defences in the Theil corridor

Figure 4. Barèges covered by a snow avalanche in 2013

3.1.2 The proposed NBS

A new approach to avalanche risk reduction is now being tested, consisting at preventing snow avalanches from the very beginning of their formation at the steeply sloped (more than 45 degrees) top of the avalanche corridors. These unfriendly environments are usually deforested because of tree establishment during the juvenile phase is challenged by snow gliding.

The proposed solution consists of slope reforestation supported with snow glide tripods. This NBS aims to increase the soil surface roughness, to prevent snow gliding and to favour tree establishment and growth. This strategy is very common in the Alpine region and, in its original version, the tripods are placed in groups where the distance between tripods should not exceed 1,5 m to mimic the clumpy structure of the Alpine forests (Rudolf-Miklau et al., 2014). Under each tripod, seedlings are planted following the "nucleation" strategy. Once planted, the resulting small patches of trees will act as focal areas for forest recovery. From the ecological point of view, nucleation is an attractive option that mimics natural successional processes to aid woody plant recolonization and to restore deforested habitats into heterogeneous landscapes, including patches of the current herbaceous and shrubby vegetation on skeletal unstable soils, and forest groves in the most favourable microsites. The final spatial pattern is thought to significantly increase soil surface roughness then slowing down snow gliding at its origin and preventing the snowpack to gain momentum (Corbin & Holl, 2012).

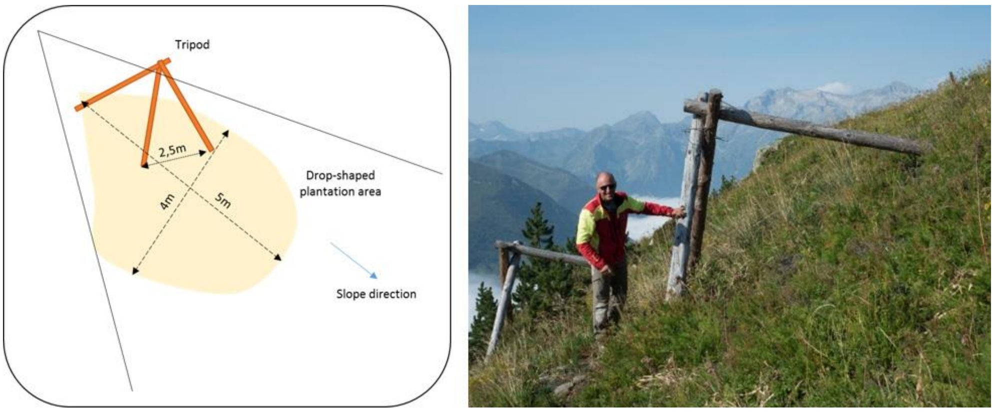

Figure 5. Plantation units under tripods (left) and a built-up tripod (right)

The original method has been tailored to fit the characteristics of the Capet Forest. 300 tripods will be stablished 10m away of each other and, under their shadow, the plantation area will be drop-shaped, as shown in Fig. 5. The 2,5 long wooden tripods will be made of non-chemically treated European larch or Douglas fir (*Pseudotsuga menziesii*) stems, both very resistant to microbial and insect attacks (the generalized use of copper will be avoided). The poles will measure about 2,5 m. The structure of the tripods is shown in Fig 5.

30 to 50 tree seedlings will be planted downhill of each tripod in a drop-shape framework. 70% of the seedlings will be *Pinus uncinata* and its stable hybrid with *P.*

sylvestris (*P. X rhaetica*), and 30% will be exotic species that have proved unable to reproduce in the Pyrenees. *Picea engelmannii* (Engelmann spruce, white spruce, mountain spruce, or silver spruce) and *Abies concolor* (Colorado fir) are among the main candidates. Contrastingly, *Pinus cembra* (Swiss stone pine) or *Picea abies* (Norway spruce, European spruce) have been discarded due to their ability to propagate and spread in the zone. The introduction of exotic species is explained to guarantee the anti-avalanche efficiency in case of high mortality of native trees by forest pests (both pines and spruces, as well as their hybrids, are threatened by *Cronartium flaccidum* "blister rust").

The *P. uncinata* seedlings will be previously inoculated with the ectomycorrhizal basidiomycete *Laccaria bicolor* to increase the survival rate. The plantation will be manually done in 40-50 cm wide micro-terraces to avoid soil disturbance (Fig. 6).

Figure 6. Plantation structures in the field. The seedlings are planted in micro-terraces with minimal soil disturbance

The measure is going to be implemented at the headwaters of the Midaou corridor, although it might also be applied to strategic points of the Theil corridor to reinforce the current anti-avalanche structures. The intervention area is about 21 ha in the altitudinal band between 1900 and 2100 m.a.s.l. (Fig. 7).

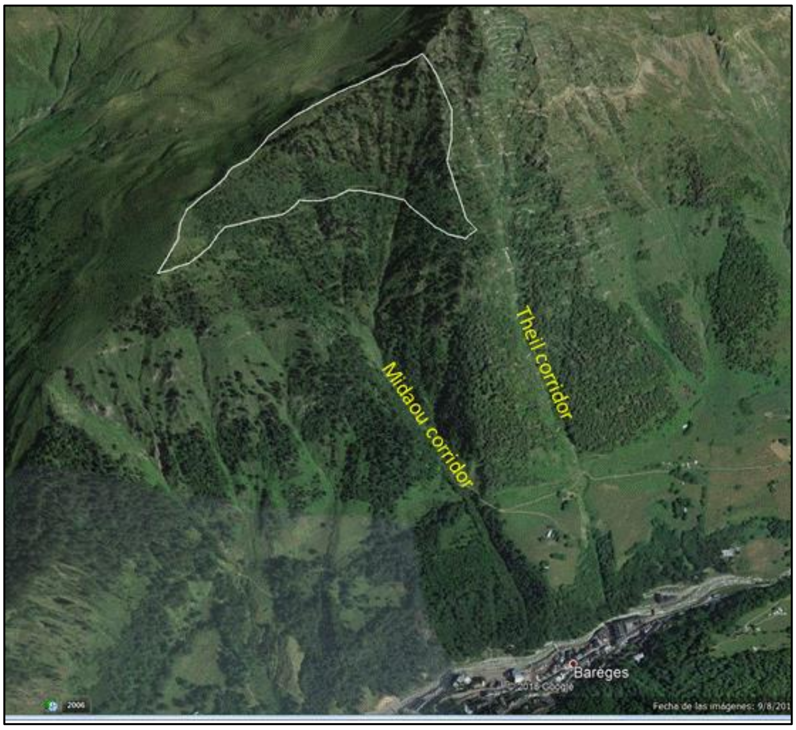

Figure 7. Perimeter of the intervention area (in white)

The zone is delimitated by the triangle delineated by the Ères Tiarrères ridge, at the top of the Miadou watershed, the crest that separates the Midaou and the Thiel watersheds, and, in the lowest leg, the forest path that crosses the "Montagne Fleurie" at 1880 m.a.s.l. (East end) to 1970 m.a.s.l. (West end).

3.1.3 Current and expected environmental scenarios

3.1.3. a. Current situation

In the intervention area, the plant cover consists of a matrix of flowery alpine prairies dominated by grasses (dominated by Festuca panniculata -alpine violet fescue-, Festuca eskia -endemic to the Pyrenees and Cantabrian range- and Brachypodium pinnatum – tor-grass), dotted with thickets of bearberry (Arctostaphylos uva-ursi), rusty-leaved alpenrose (Rhododendron ferrugineum), bilberry (Vaccinium myrtillus), heather (Calluna vulgaris) and decumbent juniper (Juniperus nana) (Fig. 8).

The rare remains of the old plantations of mountain pine are only visible in the ridges and rocky outcrops (Fig. 9a) while spots of mixed forest of pines and European larches can be found in the lower part of the hillside (Fig. 9b).

Figure 8. Prairies and bushes cover the intervention area

Figure 9. Small mountain pine spots in the ridges of the top of the Midaou avalanche channel (a); mixed forests of Pinus uncinata and Larix decidua in the lower part of the channel (b)

Only where the snow rakes have performed well (most often in the Thiel avalanche channel), soil starts to stabilize, which is indicated by clumps of young aspens (*Populus tremula*), silver birches (*Betula pendula*) and mountain ashes (*Sorbus aucuparia*) (Fig. 10).

Figure 10. Soil stabilization in the Thiel corridor, as proved by the presence of dense 25-year-old groups of aspens, silver birches and mountain ashes below the snow rakes.

3.1.3. b. Forecasted scenarios

The post-operational forecasted scenarios in the medium and long term emerged from the interaction of forest experts of the CREAF and the French Forest Service.

- *In the medium term* (30 years). Based on the observed plant dynamics, we can expect that the $10m^2$ of protected plantation below each tripod will be successful and that the current pine forest area will increase by 3000 m^2 (300 tripods x $10m^2$ of reforested soil below each tripod). Given the slow soil stabilization and low recruitment rate, expansion beyond the limits of the plantation framework is not expected to be significant at this time. However, the increased soil surface roughness will cooperate to soil stabilization in the open spaces between the plantation units. We postulate that these open spaces will behave as the areas successfully protected by the anti-avalanche rakes of the Thiel corridor (Fig. 10) and that 25 years after the implementation of the NBS, the dominant matrix between tripods will look much like the aspen, silver birch and mountain ash thickets found in the Thiel Channel.

- *In the long term* (100 years). Within 100 years, the mountain pine forest is expected to cover the intervention area, with environmental characteristics comparable to the current 100-year-old pine forest coppices remaining in the hillslope.

3.1.4 Environmental indicators applicable to the case of the Forêt de Capet

Table 5 shows the selection of indicators applicable to the Barèges study case from among the indicators tool-box described in section 2.2.

Table 5. Environmental indicators applicable to the Barèges and Sta Elena study cases

ECOSYSTEM COMPARTMENT	CRITERION	INDICATOR
Soil	Belowground C sequestration	Total organic carbon in topsoil
		Carbon sequestration: chemical protection
		Carbon sequestration: physical protection
	Physical resilience	Soil Loss: water erosion
		Soil erodibility: aggregate stability
		Soil water holding capacity
	Fertility	Soil nutrients
		Soil texture
	Biodiversity provision	Carbon and nitrogen mineralization by soil food webs
		Ecosystem stability
		Microbial diversity
		Microbial functional diversity
		Invertebrate functional diversity
		Microbial community level physiological profiling
Vegetation	Aboveground C sequestration	Aboveground tree carbon stock
	Biodiversity provision & treats	Shannon Index
		Invasive species
	Soil protection	Total vegetation cover
		Non-woody plant cover
	Wildfire risk mitigation	Plant Moisture Index
		Plant Flammability Index
Green Infrastructure	Landscape connectivity/fragmentation	Hanski's Index

The base-line and foreseeable values of all indicators selected for this study case are being calculated, to the exception of those related with wildfire risks.

Including the “wildfire risk” sub-criterion in the post-operational monitoring plan is highly recommended. Wildfire risk is very variable over time, with the highest values expected when high temperatures and evapotranspiration or electric storms coincide with great volumes of dry flammable plant biomass. Therefore, it does not make sense to estimate now the “plant moisture” base-line value, although its post-operation value should be measured every year from June to September, the months with most dangerous climate conditions (https://www.annuaire-mairie.fr/ensoleillement-bareges.html).

The calculation of the “plant flammability” index will depend on the availability of data on the flammability of the particular species that will colonize the hillside over forest maturation. Currently, this information is not available for most plant species present or foreseeable in the zone, so we have avoided making speculative calculations.

3.1.5 Assessing the indicators' base-line

3.1.5. a. Assessment methodology

Figure 11. Sampling campaign in the Capet Forest

To assess the base-line value of the remaining soil and vegetation indicators, a field campaign was carried out in September 2019 (22nd to 24th).

The campaign was successfully achieved thanks to the cooperation of the Land Restoration Service for Mountainous Regions of the French National Forestry Office (ONF-TRM) that provided helicopters for transportation of samples and researchers, personnel for sampling, and shelter in their mountain camp (Fig. 11).

We selected 32 sampling points (8 per vegetation type) corresponding to each of the four plant cover types identified in the Midaou micro-watershed (table 6).

Table 6. Geographic coordinates and elevation (m.a.s.l.) of the sampling points in the Midaou channel

Environment	Label	Lat	Long	m.a.s.l.
Prairie	Pr1	42° 54.576"	0° 03.322"	2059
Prairie	Pr2	42° 54.582"	0° 03.314"	2058
Prairie	Pr3	42° 54.585"	0° 03.379"	2075
Prairie	Pr4	42° 54.567"	0° 03.511"	2023
Prairie	Pr5	42° 54.478"	0° 03.320"	1911
Prairie	Pr6	42° 54.435"	0° 03.232"	1873
Prairie	Pr7	42° 54.591"	0° 03.487"	2040
Prairie	Pr8	42° 54.585"	0° 03.517"	2046
Shrubs	Mt1	42° 54.575"	0° 03.304"	2057
Shrubs	Mt2	42° 54.565"	0° 03.310"	2046
Shrubs	Mt3	42° 54.563"	0° 03.479"	1988
Shrubs	Mt4	42° 54.593"	0° 03.449"	2044
Shrubs	Mt5	42° 54.598"	0° 03.459"	2044
Shrubs	Mt6	42° 54.589"	0° 03.502"	2043
Shrubs	Mt7	42° 54.581"	0° 03.556"	2039
Shrubs	Mt8	42° 54.568"	0° 03.607"	2066
Pine groves	Pin1	42° 54.570"	0° 03.327"	1913
Pine groves	Pin2	42° 54.602"	0° 03.397"	2095
Pine groves	Pin3	42° 54.511"	0° 03.272"	1981
Pine groves	Pin4	42° 54.527"	0° 03.367"	1970
Pine groves	Pin5	42° 54.542"	0° 03.397"	1989
Pine groves	Pin6	42° 54.555"	0° 03.550"	2006
Pine groves	Pin7	42° 54.590"	0° 03.465"	2042
Pine groves	Pin8	42° 54.586"	0° 03.536"	2048
Aspen & Birch groves	Bet1	42° 54.519"	0° 03.297"	1993
Aspen & Birch groves	Bet2	42° 54.553"	0° 03.417"	1942
Aspen & Birch groves	Bet3	42° 54.555"	0° 03.625"	2047
Aspen & Birch groves	Bet4	42° 54.453"	0° 03.640"	1933
Aspen & Birch groves	Bet5	42° 54.423"	0° 03.655"	1885
Aspen & Birch groves	Bet6	42° 54.493"	0° 03.477"	1902
Aspen & Birch groves	Bet7	42° 54.495"	0° 03.406"	1914
Aspen & Birch groves	Bet8	42° 54.382"	0° 03.123"	1948

To distribute the points, we avoided the western sector of the intervention area, where the base-line is altered by the plantations that began one year ago. In the central and eastern zones, the sampling points were spaced equidistantly along three parallel paths that go through the ridge and the lowest and middle part or the intervention zone (Fig. 12).

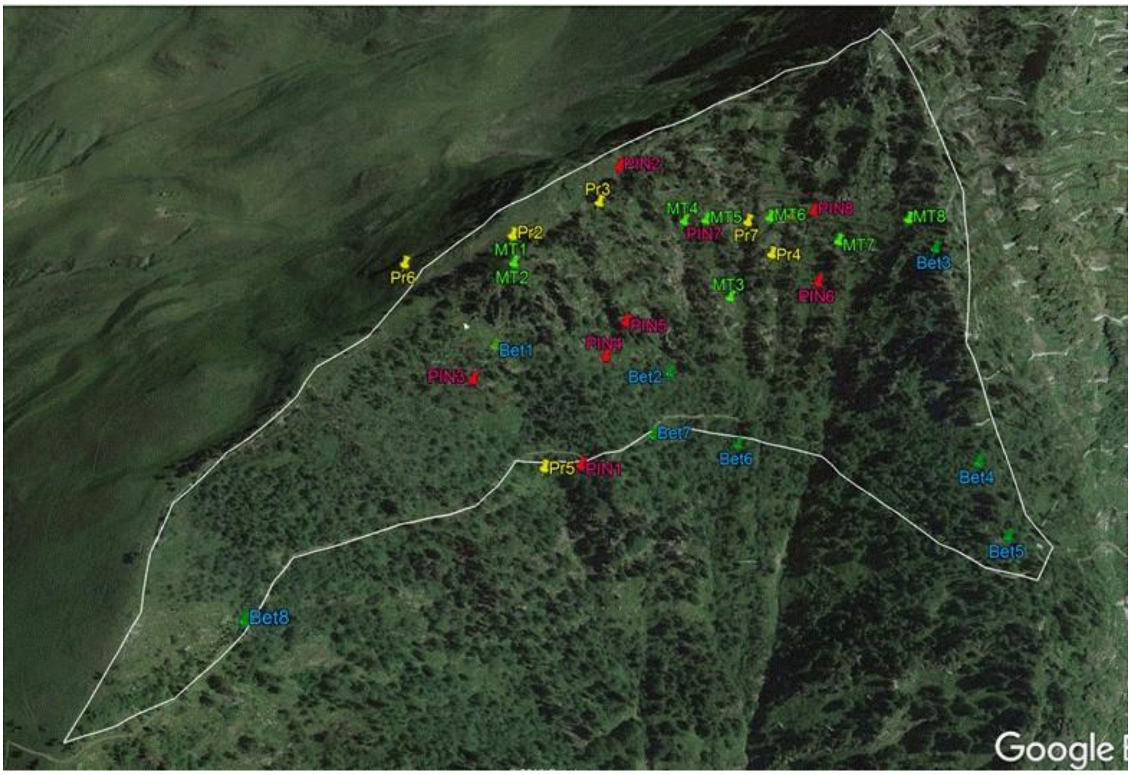

Figure 12. Situation of the sampling points in the Midaou channel

For soil indicators, three contiguous samples (5 cm in Ø and 15 cm deep) were extracted at each sampling point. A first sample was allocated to physical and chemical analyses, a second one was allocated to micro-arthropod extraction, and a third one to microbial biodiversity and micro-invertebrates (nematodes and protists). A small cylindrical soil core was also extracted from half of the sampling points for bulk density determination.

For vegetation, at least one botanical inventory was made at each sampling point that included relative soil coverage per species and average height. In the pine groves, cores were extracted from the trees with an increment corer for dating.

3.1.5. b. Preliminary results

At the moment of writing this report, the available data per vegetation cover include: (a) plant biodiversity (b) soil stoniness, root biomass and bulk density, (c) soil water holding capacity, (d) protozoa density, and (e) microbial functional diversity. Chemical and physical soil analyses, trophic web C completion and molecular analysis of microbial biodiversity are ongoing.

3.1.6 Modelling the post-operation indicators' value

To simulate the state of the indicators in the whole area affected by the NBS, we will calculate the area expected to be occupied by prairie, shrubs, aspen and birch groves and pine forest in the middle and long term. Once this done, we will extrapolate the calculated (per m^{-2}) value of our indicators to this surfaces to obtain the value of the indicator for the whole area (e.g., we will calculate total soil C content in the whole restored area by multiplying the grams of C per m^{-2} obtained from our analyses for the soil below each plant cover type by the area (in m^{-2}) attributed to each type at a given date, and then will sum all products. The same method, with the required adaptations, will be applied to all indicators.

3.2 The case of the Santa Elena road cut (Biescas, Spain)

3.2.1 The problem

The study case is an unstable cutting in the transnational A-136 road from Biescas (Spain) to Laruns (France). The road cut is located 4,7 Km north of Biescas (42.659479, -0.323979, 1060 m.a.s.l.), and is excavated perpendicular to a Quaternary moraine produced by the Gállego glacier. The moraine lies on top of Eocene flysch deposits (Barrère 1966). These glacial sediments consist of disorganized-looking accumulations of clays and sands with clasts and blocks of varying dimensions.

The 35 m high cutting is triangularly shaped with a base about 150 m long (Fig. 13). The surface is highly uneven and scarcely vegetated, and rock falls are frequent, that is a great threat for the very busy road.

Figure 13. Front view of the Santa Elena road cut

3.2.2 The proposed NBS

The proposed NBS is an adaptation of a successful restoration undertaken in 1903 in the 160-ha watershed of the Arratiecho torrent (Biescas, 42.629104, -0.308481) over colluvial flysch sediments, with an average gradient of 53% (Fábregas et al., 2014).

At the beginning of the 20th century, the watershed was deforested and totally degraded (Fig. 14). The works included the stabilization of the hillsides by terracing, the drainage of the rainwater and the reforestation of the terraces mainly with *Pinus sylvestris*. Restoration proceeded in 1903-1904.

The whole watershed was restored by 2015 and, currently, is successfully integrated in the surrounding landscape. The erosion rate is much reduced, and the area is a popular terrain for recreational uses (Fig.15).

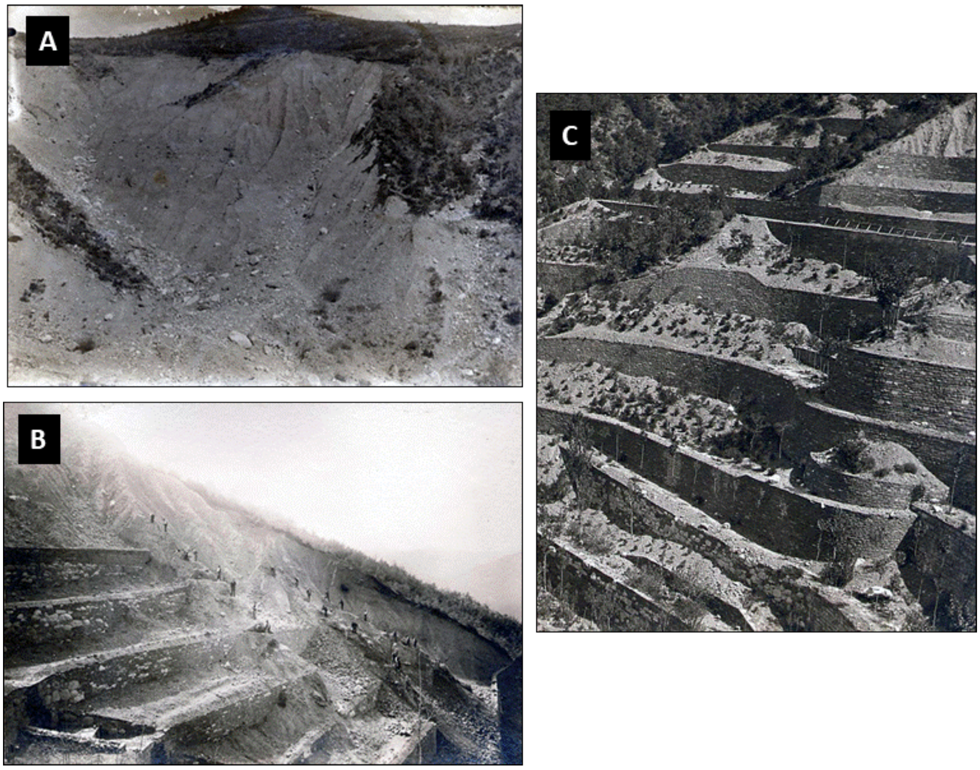

Figure 14. The Arratiecho watershed in (a) 1902-1904, and during its restoration in 1903-1904 (B-C) (Pictures from the Tomás Ayerbe collection)

Figure 15. Restoration works in 1904 (Picture from the Tomás Ayerbe collection)

The restoration method applied in Arratiecho is going to be adapted to the dimensions of the Santa Elena road cut. Although details still are under debate, it's clear that, after cutting sanitation, the stable rocky outcrops will be spared to guarantee heterogeneity and that terracing, and water drainages will be implemented before revegetation. The opportunity of building-up a retention wall at the foot of the foot is being evaluated.

3.2.3 Current and expected environmental scenarios

3.2.3. a. Current situation

The road cut surface measures 2920 m^2. At present, 53% of this surface is bare soil, 20% is covered by low shrubs and the remaining 27% is occupied by clusters of tall shrubs.

From the point of view of plant species composition, the road-cut is very heterogeneous and includes several units representing different degrees of the erosion/stabilization equilibrium (Fig. 16). At the base, thanks to the accumulation of sediments and available water, the sediments are relatively stabilized by plant thickets dominated by *Hippophae rhamnoides (*common sea-buckthorn) and *Salix caprea* (goat willow).

H. rhamnoides typically grows on wet sandy and gravel soils. Its presence indicates substrate instability but, at the same time, the plant is a powerful soil stabilizer. This is a re-sprouting species and a very good soil fertilizer thanks to its association with a variety of microbial groups (*Frankia* and mycorrhizal *Glomus* species among other) (Kumar & Sagar, 2007); *S. caprea* is associated to diazotrophic microorganisms (bacteria and archaea) that fix atmospheric nitrogen gas into usable forms for plants. Both species are interesting for their use in the revegetation of the road-cut.

Figure 16. Vegetation types in the Santa Elena road-cut and neighboring slopes over moraine sediments. Low shrubs (A, B); tall shrubs on sediment deposits (C, D, E, F, G); 40-year-old forest (H) and 5-year-old low forest (I) in the steeply SE side of the moraine

3.2.3. b. Forecasted scenarios

In the absence of further details about the previewed intervention, the medium- and long-term scenarios for the Santa Elena road cut we are considering are the result of interaction between the CREAF researchers and the staff of the "Espacio Portalet" (AECT) responsible for carrying out the work. The choice of "reference" ecosystems to model the state of the restored cutting in the medium and long term has been complicated because of no comparable environments (in terms of soil, aspect, altitude, microclimate and forest type) are present in the region. It would have been desirable to refer the post-operation progress of the cutting to the restored watershed of Arratiecho, but differences in substrate (flysch sediments in Arratiecho *vs* glacial till sediments in the Santa Elena road cut made it unadvisable.

- Therefore, *to model the state of soil and vegetation in the road cut in the short term* (5 years), we have taken as reference the South-East slope of the moraine, about 25 meters away from the cutting (vegetation unit I in Fig. 16). Unit I is located below an electric power line and, for safety reasons, the underlying fringe is deforested every five years which maintains the plant community always younger than five.

- *To model the state of the environmental indicators in the medium term*, (40 years) we have taken as reference the mixed forest (*Pinus nigra* and several deciduous tree species) that grows by the cutting in the south-east slope of the moraine (vegetation unit H in Fig. 16). The conditions aspect and topography conditions are comparable to those expected for the cutting after restoration, and the age of the vegetation (about 40 years) is well documented from pictures and public works registers.

3.2.4 Environmental indicators applicable to the Santa Elena road cut case

The indicators selected for application to the Santa Elena study case are the same that for the Capet Forest (see table 3). As in this case, and for the same reasons (explained in section 3.1.4.), the "wildfire risk" sub-criterion indicators are not being calculated by our team, although their inclusion in the post-operation program is recommended, particularly in view of the forecasted escalation of drought intensity and duration in the Iberian Peninsula. Data about the rainfall and temperature pattern in Biescas are available from: https://www.aragon.es/-/clima-/-datos-climatologicos#anchor1.

3.2.5 Assessing the indicators' base-line

3.2.5. a. Assessment methodology

To assess the base-line of the environmental indicators at the road cutting, as well as to quantify their values in the reference vegetation units for further modelling, we conducted a field campaign in September 25th to 27th 2019.
We successfully sampled the cutting thanks to the collaboration of experts in rope access work provided by AECT (Fig. 17).

For each vegetation type identified in the cutting (bare soil, short shrubs, tall shrubs) and for each of the two neighboring reference forest environments (units I and H), we selected 8 sampling points for soil sampling. 18 botanical inventories were made in the road cut and in unit I. In unit H, botanical inventories were substituted by forest inventories.

The samples area being processed now, and the lab results will be extrapolated to the cutting scale with the help of drone images provided by AECT.

Figure 17. Soil sampling in the Santa Elena road cut

3.2.5. b. Preliminary results

The currently available data inform about (a) Plant biodiversity, (b) soil stoniness, root biomass and bulk density, (c) soil water holding capacity, (d) protozoa density, (e) microbial functional diversity and (f) micro-arthropod density. Chemical and physical soil analyses, trophic web C completion and molecular analysis of microbial biodiversity are underway.

3.2.6 Modelling the post-operation indicators' value

The method to simulate the state of the indicators in the whole area affected by the NBS, has been already explained in section 3.1.6. In this case, for the short-term scenario, we will assume that a percentage (to be discussed with the AECT staff depending on the final shape of the cutting surface) of the cutting area will be occupied by tall shrubs and the remaining proportion by vegetation belonging to the I unit type. For the middle term scenario, we assume that the whole cutting area will be stable and colonized by pines, and that the environmental conditions will be similar to those in the H unit.

3.3 The case of the agricultural area of the Massaciuccoli Lake (Lucca, Italy)

3.3.1 The problem

The Massaciuccoli Lake (Lucca, Italy, 43.9833379, 10.333081) and associated marshes constitute one of the most important Tuscan Ramsar wetlands. The area is included in the Tuscan regional park "Migliarino-San Rossore-Massaciuccoli" (Fig. 18) and makes part of the Natura 2000 network as a Special Area of Conservation recently approved and named "Lago e Padule di Massaciuccoli".

Figure 18. Situation of the study site in the protected area of the Massaciuccoli Lake

The Massaciuccoli Lake is of coastal origin and is separated from the shore line by a sandy dune. The lake himself is shallow (no more than 5m deep) and measures about 7 km^2. The surrounding palustrine zone (about 13 km^2 area) has been managed from Roman times and, since the fourteenth century has undergone repeated attempts of reclamation (Linoli, 2005). Since 1930, the lake basin is drained by a complex network of artificial channels, ditches and pumping stations. When reclamation started subsidence began (2- 3 m in 70 years) leaving the lake perched above the drained area, now 0 to -3 m below the sea level. Subsidence persists at a rate of about 3 to 4 cm yr^{-1} (Pistocchi et al., 2019) and is caused by peat porosity decrease following desiccation and, under the warm Mediterranean climate, also by biochemical oxidation and humification of soil organic matter following soil aeration by tillage (Serva & Brunamonte, 2007).

In the lake, most environmental problems (eutrophication, salinization, over-exploitation of the groundwater, hydraulic risk and presence of exotic species) are attributable to industrial agriculture. Soil particles and agrochemicals reach the lake and concentrate there due to the particular functioning of the hydraulic network. In winter, the lake collects waters from the surrounding areas by means of the network of artificial channels (Fig. 19) while, in spring and summer, the water is returned from the lake to the agricultural surrounding areas for irrigation, thus recirculating the water that is more and more enriched in suspended solids (mainly eroded soil particles), nutrients and agrochemicals.

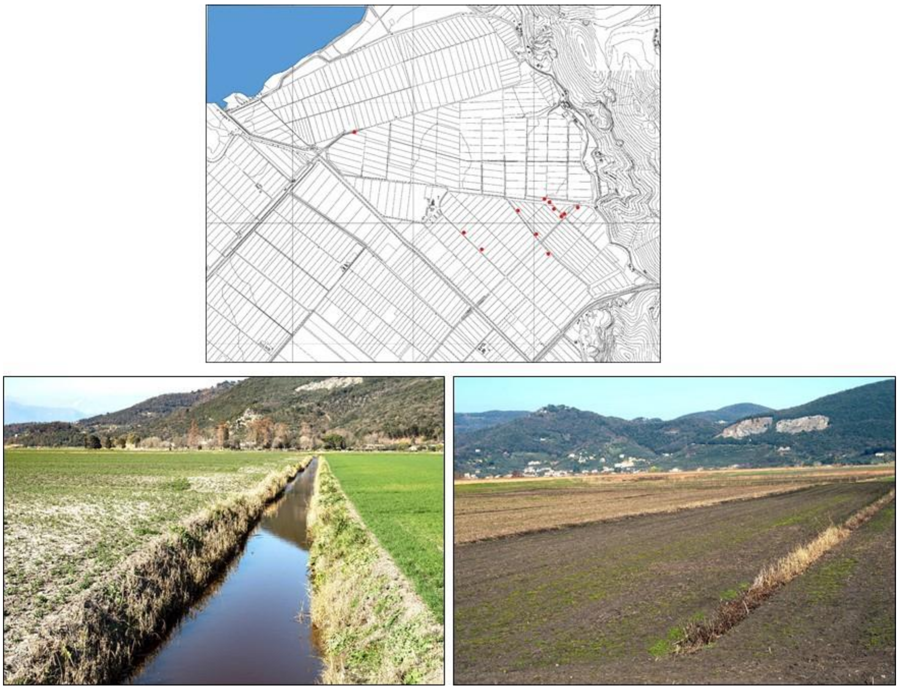

Figure 19. Drainage network of the study site (above); primary (below, left) and secondary (below, right) drainage channels

3.3.2 The proposed NBS

The proposed NBS is intended to minimize the inputs of soil materials and associated pollutants to the network of draining channels (and, finally, to the lake) from the agricultural area surrounding the Massaciuccoli Lake.

The measure will be applied to the area comprised between the Fossa Nuova Channel and the Fosso Boccalli. Previous to application to the whole area, pilot tests will be conducted in a small zone, in the south sector of the farmlands (blue square in Fig. 20).

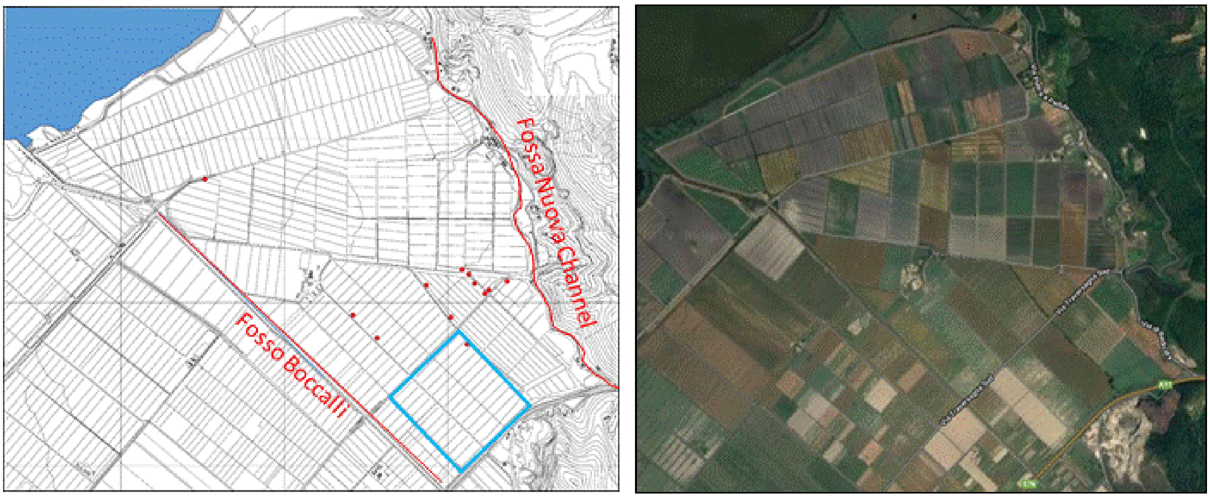

Figure 20. Area of application of the NBS, between the Fossa Nuova and Fosso Bocalli channels. The pilot area is delimitated by a blue square in the South-East part of the agricultural zone

The NBS will be to implement vegetative filter strips (VFS) along the tertiary drainage channels of the target zone.

Vegetative filter strips are land areas of either indigenous or planted vegetation (usually grasses), installed down slope of the crop land to filter nutrients, sediments and pesticides from the runoff before it reaches the water system.

VFSs are proven effective for the removal of sediment and other suspended solids from surface runoff, provided that water flow is shallow and uniform and the VFS have not been previously inundated with sediment (Dillaha et al., 1989). Other important factors affecting the effectiveness of the filters are the dimensions (length and width) of the filter (Abu-Zreig et al., 2004), the kind of the incoming pollutant, slope, volume and type of water flow and vegetation characteristics.

At the time of writing, many details of the filters (plant composition, location, size) are still being discussed in the living labs together with potential complementary measures, specifically the implementation of more sustainable agricultural practices, including cover crops.

3.3.3 Current and expected environmental scenarios

At the pilot stage, the NBS will be applied to a very small part of the study site. In order to deliver data for further extension of the results to the whole study area, we are describing the whole agricultural zone and will evaluate the base-line value of the environmental indicators in a north-south band starting in the south shore of the lake and ending in the A-11 road (Fig. 21).

3.3.3. a. Current situation

From previous field works (unpublished data provided by Nicola Silvestri, Università di Pisa) we know that, from the point of view of the soil, the study area can be divided in three zones (Fig. 21) of different soil organic matter (SOM) content.

In the high and middle SOM content zone, soil in peaty and soil organic matter content is as high as 30%-40% and 15-30% respectively. At the other end of the zone, SOM content ranges from 3 to 4%. Soil pH describes a N-S transect from acidity (pH about 4 by the lake) to basicity (pH about 8 in the southernmost end). The water table is maintained by pumping stations at a level ranging from 0.40 to 0.60 m (Pellegrino et al., 2015). Therefore, the upper soil layer is only occasionally subjected to water saturation. The distance between the water table and the soil surface also increases with distance to the lake and depends on the season. During our sampling campaign, in the fall of 2019, it was reachable in some points of the study site at a depth of 20 cm.

Also, from data provided by Dr. Silvestri, we know that the land use map of the area has undergone substantial changes in recent years under the stimuli of the EU Common Agricultural Policy for crop rotation. Indeed, in 2012 an important proportion of the study area (mainly in the north part) was occupied by stable corn crops while, in the south part, the traditional wheat-sunflower rotation system was the dominant land use. From the 2016-2019 land use maps (we could not find data for 2013/14/15) we know that from 2016 until present dates, a part of the stable corn fields is being managed in rotation with soy bean, with important consequences for soil quality (Fig. 21).

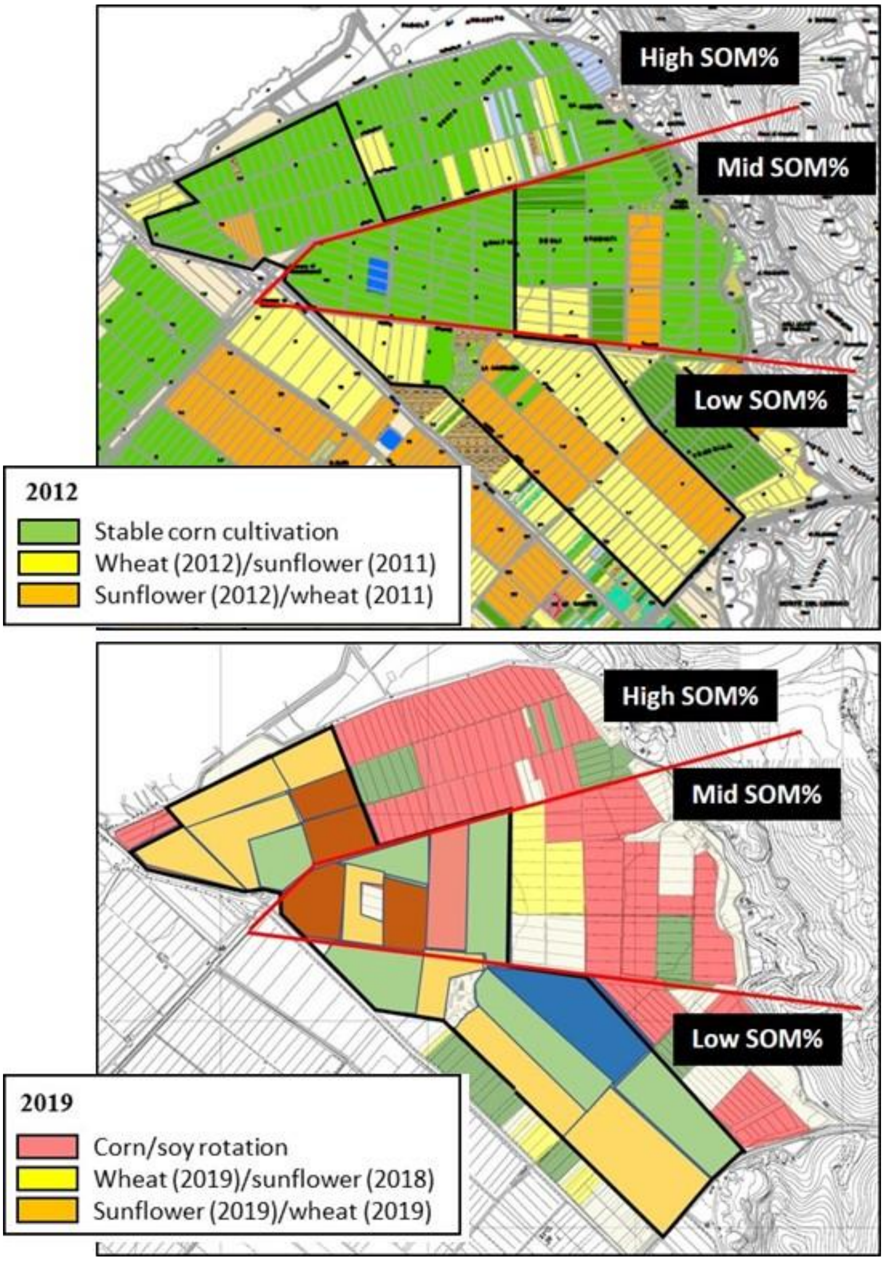

Figure 21. Land use (in 2012 and 2019) and soil organic matter content in the study site. The red line delimitates three zones of low, mid and high SOM content respectively. The thick black line delimitates the "Constanza" agricultural farm (see text for explanation)

The totality of the area is cultivated to the smallest corner, except for the bands of artificial grassland fringes that protect the embankments (made of unknown compacted soil materials) alongside the main channels and some very compacted soil fringes in the periphery of the crop units let unseeded to allow machinery access (Fig. 22).

Figure 22. Non-cultivated fringes in the study area: embankments alongside the main channel (left) and vegetated machinery accesses to the fields (right).

3.3.3. b. Forecasted scenarios

The forecasted scenario includes vegetated strips alongside the tertiary drainage channels of the agricultural area. The set-aside area will depend on the number of channels to be protected as well as of the width of the strips that is not yet defined. On the basis of previous erosion studies in the area (Silvestri et al., 2017), one can expect that the beneficial effect of this measure will be greater in the southern than in the northern zone of the agricultural area, since soil are more vulnerable to erosion in the south.

3.3.4 Environmental indicators applicable to the Massaciuccoli Lake case

The indicators to be applied to this study case are shown in table 7.

Table 7. Environmental indicators to be applied to the Massaciuccoli study case

ECOSYSTEM COMPARTMENT	CRITERION	INDICATOR
Soil	Belowground C sequestration	Total organic carbon in topsoil
		Carbon sequestration: chemical protection
		Carbon sequestration: physical protection
	Physical resilience	Soil Loss: water erosion
		Soil erodibility: aggregate stability
		Soil water holding capacity
	Fertility	Soil nutrients
		Soil texture
	Biodiversity provision	Carbon and nitrogen mineralization by soil food webs
		Ecosystem stability
		Microbial diversity
		Microbial functional diversity
		Invertebrate functional diversity
		Microbial community level physiological profiling
Vegetation	Soil protection	Non-Woody plant cover

In this study case, only soil indicators are proposed for NBS evaluation and monitoring. To control sediment exportation to water, vegetated strips can be made of wooden or herbaceous plants and, according to the information available at this point of the living lab process, the second option is preferred to facilitate implementation and yearly maintenance of the strips. Carbon sequestration in herbaceous vegetation mostly occurs in soil, in the form of roots and mineralized root exudates and death aerial parts, and carbon is assumed to be only temporarily retained in the aboveground plant parts. Therefore, carbon dynamics will be followed only in soil and vegetation will be only considered as a tool for soil protection to be included to model effects of the NBS on soil loss.

3.3.5 Assessing the indicators' base-line

3.3.5. a. Assessment methodology

On October 28-31/2019, a sampling campaign was launched to assess the current value of the selected soil indicators for the Massaciuccoli Lake case. The date was chosen in order to typify all fields during their rest period, independently of the crop type. The fields were not yet sown but some of them had already been tilled. Therefore, "recent tillage" will be included in our data treatment as an explanatory variable.

As said above, crop management has evolved recently towards rotation and two main land use types are now present in the area: wheat/sunflower rotation and corn/soy rotation. To cover these main types of land-use history and the organic matter, soil texture and acidity classes present in the study area, 53 sampling points were distributed in 14 fields along three N-S transects, one per SOM content zone (Fig. 23).

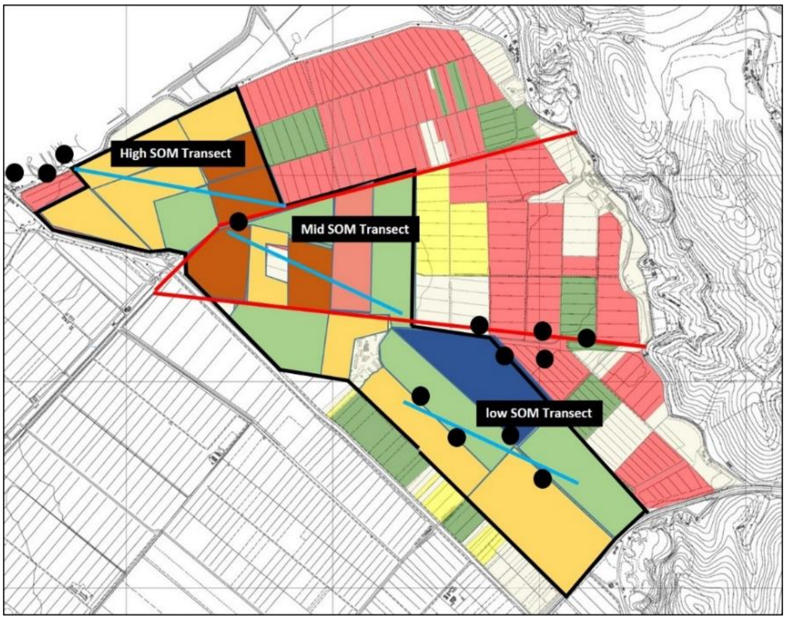

Figure 23. Sampling plan in the Massaciuccoli agricultural area. The three blue lines indicate three sampling transects. The blank dots show the sampling points for herbaceous plant communities on non-cultivated soils (see text for explanation). The red line delimitates three zones of low, mid and high SOM content respectively. The thick black line delimitates the "Constanza" agricultural farm (see text for explanation).

All samples were taken within the boundaries of "la Constanza" farm, because of this was the only sector of the study site for which information about land use and management was updated and available from the owners.

At each sampling point, four soil cores were taken and allocated to physical and chemical analyses, microbial diversity and functioning, food webs and bulk density respectively.

3.3.5. b. Preliminary results

The samples are being analyzed at the time of writing. Raw data about soil stoniness, bulk density, soil water holding capacity, microbial metabolic profile, and protozoa carbon density are already available.

Plot-scale simulations have already been submitted to the 2019 MUSLOC ("Multi-scale analysis of slopes under climate change. A cross-disciplinary workshop") conference hold in Barcelona (Spain) from 19 to 20 September 2020.

To evaluate changes in soil environmental services attributable to the proposed NBS, we are working in two ways:

(a) we are measuring the value of the selected soil indicators in spots where the plant cover is functionally comparable to the expected in the future vegetation strips. The resulting values will be extrapolated to a spatial scale once we know the dimensions and exact location of the strips. The measured pre-operational and post-operational values will then be compared. To predict the value of the indicators in the strips, we have used as proxies their value in the very rare spots where the herbaceous vegetation is still preserved. The approximated location of the sampling sites is shown in Fig. 23.

(b) Effects of the strips on reducing transport of solids and their associated contaminants from the crops to the water channels is being modelled both for the pre-operative and the post-operation scenarios. However, we strongly advise the proponents of the NBS (the *Autorità di Bacino del Fiume Serchio*) to commission field measurements of the suspended solids and pollutant burden in the run-off before and after the strips are implemented, in order to calibrate the model and to have a realistic measure of the NBS efficiency. To avoid delaying the construction of the vegetated strips, current erosion may be measured from simulated rain tests.

For this study case, we are considering a unique future scenario without considering middle or long-term effects. This is since grass is expected to stablish and the vegetated filters to be effective since the first growth season after seeding and must be artificially managed each year thus impeding plant evolution and maturation of the grass community and underlying soil.

3.4 The case of the Jorekstad flood barriers (Oppland County, Norway)

3.4.1 The problem

Near Jorekstad, at the junction of the Gause and Gudbrandsdalslågen rivers, farmland and sports facility are protected from flooding of the Gausa River by flood embankments built-up from the late seventies (Fig. 24).

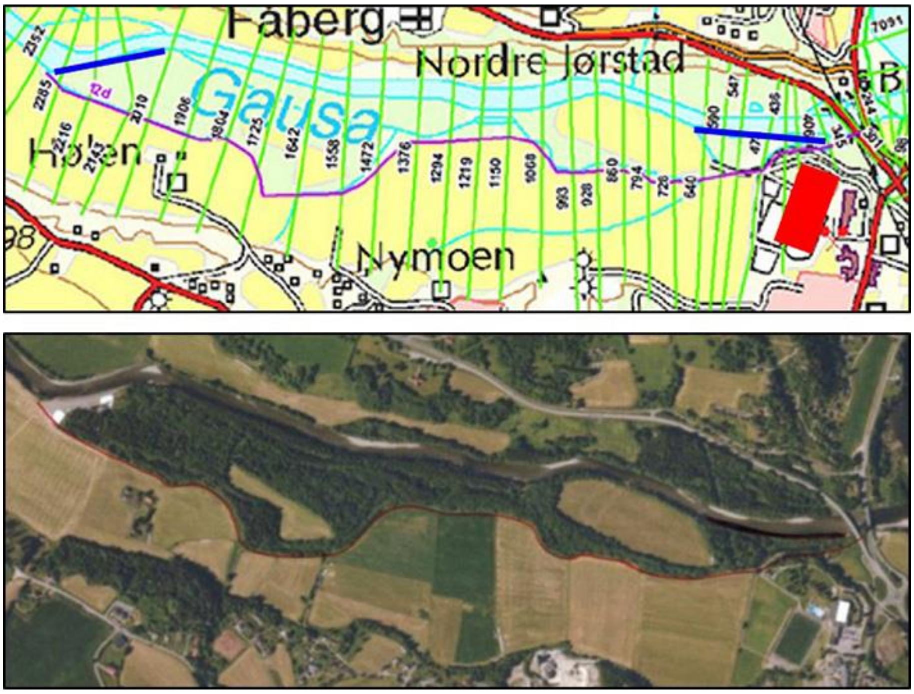

Figure 24. Map and aerial image of the study area. In thick blue lines, the old barriers; in purple (above) and red (below), the proposed receded new barrier. The red square indicates the Joresktad sports arena

The barriers are now old and deteriorated. They are not efficient and contribute to narrow the river flood plain then increasing the water speed and the hydrological risk downstream.

From the environmental point of view, constructing the barriers caused a noteworthy reduction of the natural value of the plant communities due to (Fig. 25):

(a) changes in river dynamics that resulted in the disappearance of the unstable sediment banks in the center of the river bed and by the shore. These sedimentary islands where occupied by thickets of *Myrmicaria germanica* and *Salix daphnoides*, both good colonizers of unstable sedimentary environments,

(b) reduced flooding of the forest vegetation of the riverbanks that triggered the progressive substitution of the riparian species by *Picea abies*, that has also been planted after logging of the natural vegetation, and

(c) water stagnation in the former flood channels, now converted into small pools (fed by the run-off from the agricultural lands) that evolve towards stinking water with "brown foam" on top during the summer.

Figure 25. Plant communities alongside the right bank of the Gausa river some years before (1959) and after (2017) the construction of flood barriers. The sedimentary banks in the center of the river bed have disappeared, and the grey alder forest has been invaded by coniferous species.

3.4.2 The proposed NBS

The proposed NBS includes the demolition of the old flood barriers and the construction of a new barrier adjusted to a return period of 200 years (Q_{200}), 2340 m long and less than 4 m high. This barrier will be receded compared to the existing structures which will increase the watercourse capacity during large floods. Furthermore, about 6 ha of new agricultural land will be incorporated into the flood zone.

3.4.3 Current and expected environmental scenarios

3.4.3. a. Current situation

We don't have yet detailed information about the environmental characteristics of the study zone. Based on data provided by the Oppland County, we know that the vegetation of the wetland corresponds to a grey alder - bird cherry (*Alnus incana - Prunus padus*) forest that is attributed great conservation value. This plant community grows on nutrient rich and wet environments that favor high diversity, including *Actaea spicata* (Bane berry), *Valeriana sambucifolia* (common valerian), *Impatiens noli-tangere* (touch-me-not), *Paris quadrifolia* (herb-Paris), *Scirpus sylvaticus*, *Matteuccia struthiopteris* (ostrich fern) and *Viburnum opulus* (Guelder rose) among other. The forested floodplain is also rich in plants listed in the Norwegian Red List for Species as “near threatened”, “endangered” or “vulnerable”, as *Trametes suaveolens*, *Salix triandra*, *Salix daphnoides*, *Myricaria germanica*, *Thalictrum simplex simplex*, *Glyceria lithuanica*, *Ulmus glabra*, *Fraxinus excelsior* and *Cinna latifolia* among other.

3.4.3. b. Forecasted scenarios

There is notable uncertainty about the environmental scenario that will follow the elimination of the current flood barriers, in particular the westernmost one.

What emerges from the observation of time series of imagery (Fig. 26) are changes in the sedimentary dynamics of the Gausa River from 1959 to 2017, with increasing colonization of the sedimentary stream banks by vegetation. Riparian forest stabilized the sediments and progressed at the expense of the communities of *M. germanica* and *S. daphnoides*. Whether this stabilization was a consequence of the local construction of barriers or the result of a variety of other unidentified factors is unknown.

Thus, two alternative post-operational scenarios are being hypothesized:

(a) the sedimentary river banks will recover and the *M. germanica* and *S. daphnoides* communities will regain their past place and substitute the riparian forest. The landscape would be similar to the one in 1959 and 1967 in Fig 26.

(b) there is no change in the sedimentary dynamics of the river; soil humidity increases in the right riverbank, and the riparian forest recovers with the help of some management addressed to lessen the importance of conifers.

Figure 26. Evolution of the riparian landscape from 1959 to 2017. The first flood barriers were built-up during the late 1970s and again in 1995.

3.4.4 Work prospect for 2020

We preview to conduct a sampling campaign in Jorekstad in the spring of 2020, after snow melt.

Previously, we should have decided the future scenario to be considered which, in turn, will determine the appropriate environmental indicators to measure/model. We rely on the Oppland County staff to get the necessary information and to find riparian forests and unstable riverbank vegetation that can be taken as a proxy of the expected post-operation vegetation in the medium and long term.

3.5 The case of the Bastan River (Barèges, France)

3.5.1 The problem

The Bastan River is a tributary of the Gavarnie River. Since the XIXth century, a number of floods of the Bastan have destroyed roads, houses and farmlands between the town of Betpouey and its confluence with the Gavarnie River in Sassis. In 2013, a very severe flooding event displaced 650.000 m^3 of materials which totally altered the local landscape and the profile of the riverbed and destroyed the riparian vegetation (Fig. 27).

Figure 27. The Bastan River near Viella (France) in 2009 and in 2019, before and after the 2013 flood.

Currently, the riverbed is occupied by rocks of different size among which invasive species grow on islands of more finely sized sediments (Fig. 28).

Figure 28. The Bastan River in the study site, in September 2019. The river bed is occupied by boulders of different sizes, and some invasive plant species are thriving.

Since 2013, many reconstruction and protection measures have been implemented in this sector of the Bastan Valley, including the construction of protective rock walls, the enlargement of the riverbed and the exportation of sediments. In order to recover the protection level existing before the 2013 flood, 200.000m^3 of materials have still to be removed upstream of Luz-Saint-Sauveur.

3.5.2 The proposed NBS

The proposed NBS is oriented to recreate a natural paving for the Bastan riverbed by producing step-pools and to restore natural and agricultural spaces in the river banks. In a first pilot phase, the measure will be implemented immediately upstream of the town of Betpouey (42.882981; 0.037581, 976 m.a.s.l.).

Different works are forecasted for the minor excavated channel (about 10 m wide) and for the remaining space in the major river bed.

In the minor central channel, step-pools will be constructed by reusing and rearranging the big boulders locally available from the riverbed and also by importing quarry blocks. Step-pools represent an attempt to progress towards the profile the riverbed will naturally adopt over a long time period (Lenzi, 2002).

On either side of this central channel, the major river bed will be elevated above its current level by burying blocks in the substrate in place and by filling the holes with fine materials and topsoil to recreate a fertile soil able to sustain grazing. The contact slopes between the lateral terraces and the excavated step-pools will be stabilized by some type (to be specified) of green walls (Fig. 29).

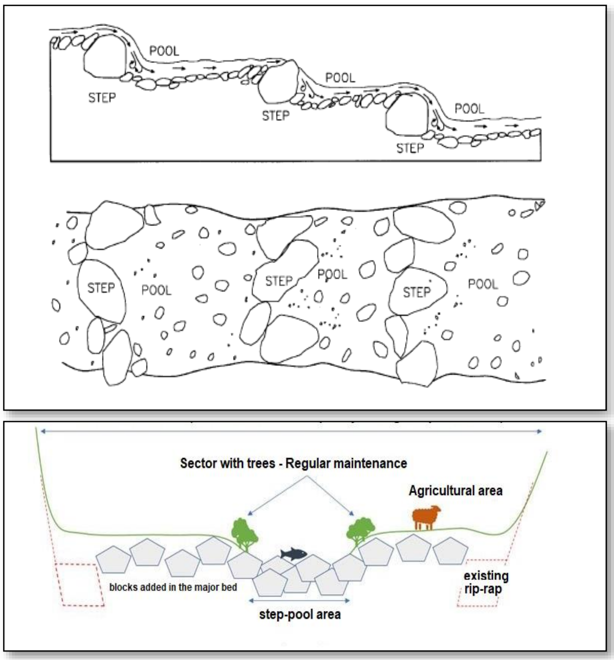

Figure 29. Above: Sketch of the longitudinal profile and zenithal view of a steep-pool channel (adapted from Lenzi, 2002). Below: Sketch of the proposed NBS provided by the proponents.

3.5.3 Environmental indicators proposed for the Bastan River case

CREAF involvement in the Bastan River study case is limited to:

- propose river quality indicators to be applied by the proponents of the NBS (or their delegates),
- give advice (if requested by the proponents) about the best options for the creation of new soils suitable for agricultural use, and
- propose indicators to evaluate the agricultural quality of the newly created soils.

The proposed river quality indicators are shown in table 8 and were in good part proposed by the UNINA researchers.

Table 8. Indicators of river quality proposed for the Bastan River

ECOSYSTEM COMPARTMENT	CRITERION	INDICATOR
Water	Biodiversity provision	Extended Biotic Index (EBI)
		Invasive alien species
	River quality	Fluvial Functionality Index (FFI)
	Water quality	Physical & chemical parameters

Concerning the quality of the newly created soils, given their agricultural use for pasture, their quality can be indirectly estimated through plant production and soil plant cover.

To <u>measure biomass production</u>, 10 to 15 sampling plots, delimitated by 0,5 m x 0,5 m squared frames will be randomly distributed in the restored area. All standing biomass will be harvested at the ground level and put in labelled paper bags. The herbaceous biomass may be set to air-dry for one week in dry conditions or may be set to dry in an oven at 100 °C for 48 hours. Total dry herbaceous biomass will be expressed in g (dry weight) ha^{-1}.

To <u>evaluate the nutritional quality of the pasture</u>, 10 to 15 herb samples (at least 100 gr each) will be harvested during the growth period by cutting the herb at ground level. The samples will be sent to specialized animal feed testing labs for analyses of, at least: dry matter, crude ash, crude protein, crude fibre, crude fat, sugar, neutral and acid detergent fibre, acid Detergent Lignin (*ADL*), soluble crude protein and digestibility and metabolizable energy.

Finally, it is also advisable to <u>monitor the evolution of soil plant cover</u> as an indicator of both soil health and protection against erosion. Plant cover can be easily evaluated by the point-contact method. In its simplest version, the method may be applied to 10 to 15 transects randomly established in the study area. Each transect can be sampled by using 5 m long measuring tapes held above the grass cover. Along each transect, a knitting needle will be positioned vertically every 20 cm and presence/absence of contact of the needle with plants will be registered. Plant cover can be expressed in % as the percentage of contact points related to total checked points (250 points per transect)

3.5.4 Recommendations for monitoring

It is advisable to measure the proposed indicators yearly and at least during the ten first years after operation. This intensity is explained by the fast dynamics of the river ecosystems. In particular, the incorrect evolution of the grass cover and the apparition of invasive species (included in the quality indicators) must be detected as soon as possible to correct soil parameters and to prevent invasions.

4 Acknowledgements

We want to acknowledge the many people who have worked generously to make it possible for us to fulfil our work compromises. In particular, we thank:

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