PHUSICOS

According to nature

Deliverable D6.4

Technical training for private companies and public authorities for NBS implementations to reduce the risk from natural hazards in mountain areas

Work Package 6 – Learning arena innovation to encourage knowledge exchange

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Note about contributors

Lead partner responsible for the deliverable:	CTP
Deliverable prepared by:	Didier Vergès
Partner responsible for quality control:	NGI
Deliverable reviewed by:	Anders Solheim
Other contributors:	Eva García (CTP); Éric Leroi (R&D); Paola Sangalli (AEIP); Pilar Andrés (CREAF); Clara Lévy (BRGM); Xavier Carbonell (ARC Mediación Ambiental)

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Summary

This deliverable, D6.4 Technical training for private companies and public authorities for NBS implementations to reduce the risk from natural hazards in mountain areas, is linked to WP6 and built upon the implementation of the NBS at four sites, as part of the large-scale Pyrenees demonstrator site: Capet Forest, Artouste, Santa Elena and Erill la Vall.

The main goal of this deliverable report D6.4 are twofold. First, the deliverable describes the content exposed during a two-day event organized on April, 11th and 12th in Laruns, France. Second, it summarises reflections raised during the event and proposes recommendations, or else soil monitoring protocols, aimed at politicians and technicians in charge of risk management who are interested in implementing NBS for facing natural hazards in mountainous areas.

The implementation of the NBS in the Pyrenees involved a large spectrum of stakeholders, public and private. The event, oriented in delivering training, disseminating and discussing results of PHUSICOS in the Pyrenees, allowed to gather a number of the stakeholders engaged in the four Pyrenean sites together with neighbouring external actors. Technical aspects and participatory process have been presented and discussed in order to point out the key lessons to be capitalized and shared, as a contribution for replicating the PHUSICOS experience of implementing NBS to face natural hazards.

The report also includes as appendixes the agenda and the participants' list to get a whole idea of the content of the event and variety of actors who participated.

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1 Introduction

1.1 Justification for a final event focused on training and experiences sharing

PHUSICOS has enabled the implementation of nature-based solutions to reduce the risk posed by extreme weather events in rural mountain landscapes at four sites in the Pyrenees, as part of the large-scale Pyrenees demonstrator site.

Throughout the implementation of these solutions, the work with partners and stakeholders has brought to light difficulties and lessons learned that Working Community of the Pyrenees (CTP; *Comunidad de Trabajo de los Pirineos*) wished to highlight in an event (Figure 1-1 Poster used to disseminate the two-days event, in French.and Figure 1-2. Poster used to disseminate the two-days event, in Spanish.where these lessons learned could be pooled and shared with the territory's public and private stakeholders. These difficulties include the administrative procedures for authorizing the works, the legal responsibilities of those responsible for the works, problems related to the definition of the projects or difficulties related to the capabilities and knowledge of local companies when it comes to implementing this type of solution to deal with natural hazards.

CTP, in collaboration with the PHUSICOS partners involved in the Pyrenees demonstrator site, organized:

- A training day on 11 April 2023, with the objective of introducing to the participants the main techniques of biological engineering, particularly adapted to mountain environments.
- A results seminar on 12 April 2023, with the objective of presenting the results obtained from PHUSICOS and discussing the performance of nature-based solutions to natural hazards in mountain areas.

Hence, the event was aimed to increase engagement of local authorities and key stakeholders into nature-based solutions (NBS) for facing natural hazards, to foster a space for free exchange between peers about challenges, successes and failures in developing NBS for natural hazards in their territories or else to enrich and learn from the exchanges and then improve the progress towards standards and regulations.

The two days were mainly intended for authorities and technicians from public forestry and road administrations, small and medium-sized enterprises in the timber and construction sectors. and consulting firms specialized on natural hazards, geotechnics, etc.

More than 150 invitations were sent to authorities and technicians of neighboring municipalities affected by natural hazards, chambers of commerce and industry of the Pyrenees, small and medium-sized companies in the timber and construction sectors, municipal, departmental and regional administrations dealing with road management and maintenance, consultancy firms and engineering offices, environmental associations, research centres, etc.

Twenty-six participants attended the training day on 11 April 2023, from territorial administrations, companies and associations. On 12 April 2023, 32 people attended the results seminar, with other participants mainly from municipal authorities.

Key presentations during the event were given by invited members of the European Federation of Soil Bioengineering (EFIB), EIFORSA, a company specialized in the timber sector, technical experts in charge of the definitions of NBS in each of the four sites intervened by PHUSICOS (Alain Bruzy, Santiago Fábregas and Carles Raïmat), the expert in participative techniques associated to the Living Labs in Santa Elena, Artouste and Erill la Vall (Xavier Carbonell) and the mayors of the villages of the four sites (Robert Casadebaig, Pascal Arribet, Jean-Louis Noguère and Sònia Bruguera). In addition, three PHUSICOS partners, Ecological and Forestry Applications Research Centre (CREAF; *Centro de Investigación Ecológica y Aplicaciones Forestales*), French Geological Survey (BRGM; *Bureau de Recherches Géologiques et Minières*) and Risk & Development (R&D; *Risques & Développement*) participated in the event and presented their work on the development of NBS at the Pyrenees demonstration site. CTP presented on behalf of University of Geneva (UNIGE; *Université de Genève*) and International Institute for Applied Systems Analysis (IIASA), who sent a presentation focused on obstacles to NBS, comparing them with grey infrastructures and examining perceptions from private contractors.

This report, deliverable 6.4, which is part of work package 6 (WP6), is then linked to WP2 - Case study sites: large scale demonstrator sites and supporting concept cases, WP3 - Service innovation: stakeholder participation through Living Labs and WP5 - Governance innovation for the design and implementation of nature-based solutions. This deliverable provides an overview of the content of the training day and highlights the main findings of the results seminar, proposing a series of lessons learned and conclusions from this two-day event.

Figure 1-1 Poster used to disseminate the two-days event, in French.

Figure 1-2. Poster used to disseminate the two-days event, in Spanish.

1.2 Brief presentation of the NBS developed by PHUSICOS in the Pyrenees

1.2.1 Snow avalanches at Capet Forest

Barèges and Sers are two villages located at the bottom of the slopes of the Capet national forest, in the Hautes-Pyrénées department, in the Pyrenees. The two villages have a permanent population of about 300 people, which doubles or triples during the summer and winter seasons, due to the attraction of winter sports in the valley.

The hazard at the site is from snow avalanches in the 'Midaou' avalanche path. The avalanches may reach the village of Barèges, and this has occurred several times in the past, the last event being in 2013. The slope and the release area have numerous old 'grey' protective structures, the first ones already from the mid 1800's, constituting a true 'museum of avalanche protection structures'. Due to the prevailing wind direction, the snowpack may rise above the approximately 4 m high existing structures. In 2013, the avalanche was initially released in the upper 0.3 m of snow, exceeding a snow height of 4 m. The grey measures are designed to protect against avalanches with a return period of 100 years. These structures are meant to co-exist with the new nature-based solutions implemented by PHUSICOS.

The nature-based solutions developed by PHUSICOS since 2020 consist of afforestation by planted trees of 9 different species (*Pinus uncinata, Larix decidua, Abies concolor, Picea engelmanii*, *Pinus cembra*, *Pinus ponderosa*, *Pinus bougetii*, *Pinus sylvestris*, *Cedrus deodora*), all proved to be best adapted to the climate and elevation (1800-2200 m asl.) of the site. The plants are either protected by 88 newly built wooden tripods (Figure 1-3 and Figure 1-4), by the existing grey structures, or by existing natural groups of trees. The wooden tripods are also meant to serve as protection structures against avalanche release. This is particularly important in barren areas with little or no existing vegetation or grey structures.

Figure 1-3. *Overview on the site of Capet Forest site.*

Figure 1-4. *Detail on a wooden tripod, next to a masonry wall, grey infrastructure.*

1.2.2 Rock fall at Artouste

The site is adjacent to the hydropower dam of Artouste, where the RD-934 road descends in sharp turns from the height of the reservoir level to the base of the dam. The site is located in the municipality of Laruns.

The hazard at Artouste (Figure 1-5) is caused by rockfall, sourced from both exposed rock ledges and loose blocks resting on the till surface in the steep slope. The slope is steep, and falling rocks often hit the road and cause hazardous situations. In 2013 a fatal accident occurred when a car received a direct hit from a rock. This road receives intense traffic and is a strategic route between France and Spain. The average traffic density at Artouste is higher than 1,000,000 vehicles per year.

The nature-based solutions developed by PHUSICOS consist of different structures made of wood and/or local stones (Figure 1-6). The solutions rely on active measures (manual stabilization and/or timber structures) to stabilize the source areas and passive measures (mixed wood and/or stone structures) to slow down and/or divert rocks in their trajectories, enhancing the protective role of the forest. Complementing NBS intervention, test facilities for rockfall NBS measures are established in both La Peña Estación, Spain, on the premises of the timber company, and at an open-field site, Gourzy, France, with similar characteristics to that of Artouste.

Figure 1-5. *Overview on the site of Artouste.*

Figure 1-6. *Detail on a wooden tripod, as an active measure.*

1.2.3 Unstable till slope at Santa Elena

The slope at Santa Elena has been highlighted as one of the high-risk locations along the A-136 road, a major route between Spain and France (called RD-934 in France). This site is located in the heart of the Pyrenean valley of Tena, attracting summer tourism for hiking excursions and in winter the ski resort of Formigal.

Many incidents involving rocks and/or debris on the road have occurred in the past along this stretch of the A-136, but few serious accidents have been reported. Speeds are often high there, and visibility is low due to the terrain, so there is little time to react if obstacles fall onto the road. The road receives intense traffic and is a strategic route between France and Spain; the average traffic density at Santa Elena is higher than 4,000 vehicles per day.

The measures implemented by PHUSICOS at Santa Elena (Figure 1-7 and Figure 1-8) consist of terraces formed by a 5-m-high dry masonry wall at the base, followed by 10 terraces constructed by logs. The log constructions are in the form of timber gabions, and these are filled with the local sediment, with a 10 cm layer of organic soil on top for planting bush vegetation on the terraces. All plants used are local and are adapted to the climate, altitude and the local geology (glacial till) (*Pinus sylvestris*, *Betula pendula, Sorbus aria, Populus nigra*, *Salix capraea*, *Hippophae ramnoides and Salix eleagnos*). *Hippophae ramnoides* is a shrub particularly recommended for stabilizing slopes; the roots spread quickly and extensively, also providing non-leguminous nitrogen fixation in surrounding soils.

Figure 1-7. *Overview on the site of Santa Elena, taken with drone, with the masonry wall and the wooden terraces at the end of the works.*

Figure 1-8. *Detail on wooden gabions during the construction.*

1.2.4 Debris flow mitigation in Erill-la-Vall

Erill la Vall is a village in the Boí valley in Catalonia, located at the bottom of a gully. The problem at the Erill-la-Vall site in Catalonia, Spain, is erosion and debris flows from a thick (>50m) boulder-rich till complex. Numerous smaller gullies feed debris into the main debris flow channel, which can eventually reach the village of Erill-la-Vall. It has been hit by debris flows in the past. Heavy rain triggers an immediate response in the surface sediments, with erosion and the downslope transport of debris and larger blocks, which are abundant in the till material. However, a piezometer at a depth of 30 m in a borehole behind the back scarp shows a response to heavy rain after 10-15 days, and this may trigger larger, deep-seated events. One occurred in 1907 after a long period of rain. The NBS are primarily implemented to mitigate against shallow events.

The measures implemented by PHUSICOS (Figure 1-9 and Figure 1-10) consist of terraces built of dry-stone walls and timber. These are constructed in the lower parts of the steepest area in the two main gullies. The terraces are to be covered with organic soil and planted with local vegetation: grass, bushes, and trees. Soil and turf from the area is used, and natural fertilizers from local grazing animals are used on the terraces. About 2,500 plants will be used, all local species (*Betula pendula, Salix purpurea, Salix caprea, Rhamnus alpina, Viburnum opulus, Corylus avellana, Prunus spinosa, Fraxinus excelsior and Salix sp.*).

Figure 1-9. *Overview on the site of Erill la Vall with the krainer walls and rock terraces at the bottom of the gully.*

Figure 1-10. *Detail on krainer wall filled with material.*

2 About bioengineering

The first day of the event introduced the main hazards present in the Pyrenees and the concept of nature-based solutions, and the focus then changed to the specificities of forest management in the Ossau and Aspe valleys. The rest of the day was dedicated to understanding the basics of bioengineering and its main techniques. A practical exercise was carried out with 1:20 scale pieces so that the participants could practice and visualize these techniques and their effects. This part on bioengineering was presented by the European Federation for Biological Engineering (EFIB) and its invited members. Chapter 2 reviews the content that was presented to the participants, and the full agenda of the two-day event is added to this report as an appendix.

2.1 Bioengineering: definition and approach

The conservation of natural resources requires the adoption of corrective or restorative measures aimed at preventing negative impacts or minimizing their effects on the natural environment.

Therefore, any restoration, rehabilitation or environmental regeneration programme must enable the reconstruction of the biological potential of the affected areas so that their reuse for other purposes or their integration into the landscape is viable.

The Society for Ecological Restoration (SER) defines this activity as the ‘process aimed at recovering the ecological integrity of the environment, based on the variability of these areas, in terms of biodiversity and ecological processes and functions, in a historical regional context, in which sustainable traditional uses are also taken into account’.

Biological engineering, bioengineering or landscape engineering can be understood as the constructive discipline that pursues technical, ecological, aesthetic and economic objectives, using mainly living materials such as seeds, plants, plant parts and plant communities, either alone or in combination with inert materials such as stone, earth, wood, iron or steel as constructive elements. These objectives are achieved by taking advantage of the multiple functions of plants and using construction techniques with a low environmental impact.

Biological engineering has its origins in the combination of forestry techniques with traditional engineering techniques; it has been developed mainly in Central Europe: Austria, Switzerland, Germany and to a lesser extent Italy and France, countries that, being part of the Alpine Arc, are traditionally sensitive to the preservation of the natural environment and try to regenerate the impacts produced by their large-scale projects, through techniques that activate or enhance natural regeneration. It is not a discipline that replaces classical engineering but should nevertheless be understood as a necessary and complementary element to conventional engineering works.

Nowadays, with changing economic models and greater sensitivity towards environmental issues and, in general, quality of life, bioengineering has great potential for intervention in the landscape and the defence of the environment. The main fields of action are:

- Reconstruction of wetlands, coastal areas, riverbanks and reservoirs.
- Interventions in mountainous areas, mainly in the recovery of landslides, slope stability and ski slopes.
- Recovery of public works, highways, gas pipelines and railway lines.
- Renaturation of mines, quarries, dumps and landfills.

2.2 Bioengineering techniques

Biological engineering comprises a series of techniques that use living plant material as a construction element, either alone or combined with inert materials, within the field of environmental restoration. Biological engineering or bioengineering is used in all areas of civil works, especially in the field of slope and bank consolidation and erosion control.

Bioengineering techniques have several functions (Begemann *et al.*, 1994): technical, ecological, landscape and economic.

Technical functions

These techniques refer to the protection and stabilization of soil through the root system. They are: protection of the soil surface against erosion due to wind, precipitation, ice and water flow; protection against falling stones; deep stabilization of the soil; elimination and absorption of harmful mechanical forces; reduction of the speed of the currents on riverbanks; aggregation and superficial and/or deep stabilization of the soil; drainage; protection against wind; favouring the accumulation of snow, sands and material drags; increasing the roughness of the terrain, thus creating a defence against avalanches.

Ecological functions

By introducing vegetation, bioengineering modifies the ecological characteristics of the intervention area. Bioengineering techniques offer results such as: improvement of the water balance through an increase in interception and thus greater water retention capacity of the soil and water consumption by plants; development of more stable plant associations in the vegetation series of the area, especially the use of native species that help to speed up the recovery of the original ecosystem; soil drainage; protection against wind; protection against immissions; mechanical disaggregation of the soil by plant roots; compensation of temperature conditions in the subaerial zone and in the soil; shading; improvement of the amount of nutrients in the soil and -consequently- an increase in the fertility of poor soils; protection against noise; increased productivity in nearby agricultural areas.

Landscape functions

These are aimed at improving the landscape, for example: restoration of scars on the landscape; integration of works and constructions into the landscape; visual screens to hide infrastructures with a strong visual impact; enrichment of landscapes by creating visual focal points and new structures, shapes and colours in vegetation.

Economic functions

Bioengineering works are not always cheaper than classical engineering ones. However, taking into account the durability of these works, including maintenance tasks, bioengineering works are usually more economical. Bioengineered works are living systems based on natural succession, i.e. they remain in equilibrium through dynamic self-regulation without the need for artificial energy input. By choosing the right techniques as well as living and inert materials, extraordinary persistence with low maintenance costs can be achieved.

Bioengineering techniques can be classified into 4 major groups:

1. Coating techniques.
2. Stabilization techniques.
3. Mixed techniques.
4. Complementary techniques.

2.2.1 Coating techniques

These are techniques designed to prevent surface erosion (Figure 2-1 and Figure 2-2 and Figure 2-3). Within this group the following sub-techniques can be distinguished:

- Sowings of various types, with or without mulch
- Hydroseeding, both herbaceous and woody species
- Use of organic blankets in sowings
- Transfer of sod or plant fragments: mainly rhizomes and stolons
- Covering with salicaceae sticks.

- Broadcast seeding.

Figure 2-1. *Coating technique: broadcast seeding in structure. Florin Florineth (EFIB, Paola Sangalli).*

Figure 2-2. *Coating technique: hydroseeding (EFIB, Paola Sangalli).*

Figure 2-3. *Coating technique: placing organic blanket. Valentín Contreras (EFIB, Paola Sangalli).*

2.2.2 Stabilization techniques

These techniques make it possible to stabilize the soil up to 2 meters deep and are based on the arrangement of woody plants obtained by vegetative reproduction and placed in horizontal rows (Figure 2-4, Figure 2-5, Figure 2-6, Figure 2-7, Figure 2-8, Figure 2-9 and Figure 2-10).

The plants must have the capacity to grow adventitious roots so that they form a framework that allows the soil to be held in place.

These techniques include:

- Willow stakes
- Sprig beds or firewood stepping stones, in soils with little cohesion
- Succession of stakes and fences
- Wicker braids
- Bank fascines
- Draining fascines
- Branch mats
- Palisades.

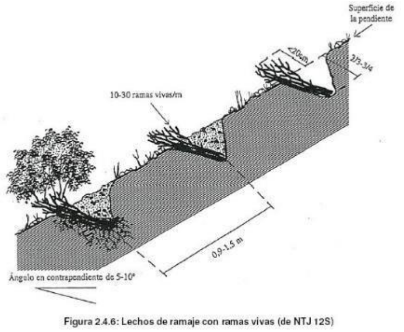

Figure 2-4. *Stabilization technique. Sprig beds scheme (Sources: NTJ 12S) (EFIB, Paola Sangalli).*

Figure 2-5. *Stabilization technique. Sprig beds photo (EFIB, Paola Sangalli).*

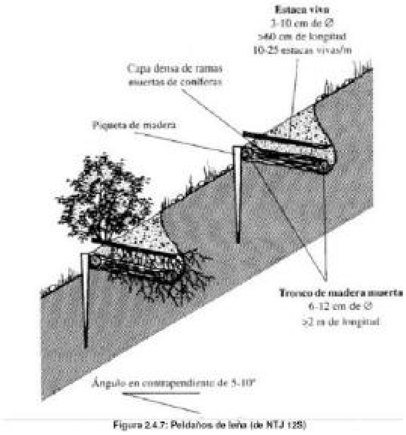

Figure 2-6. *Stabilization technique. Wooden steps diagram. (EFIB, Paola Sangalli).*

Figure 2-7*. Stabilization technique. Wooden steps photo. (EFIB, Paola Sangalli).*

Figure 2-8. *Stabilization technique. Wicker braid photos from Florin Florineth (EFIB, Paola Sangalli).*

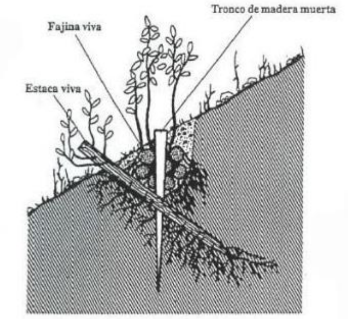

Figure 2-9. *Stabilization technique diagram (Source: NTJ 12S) (EFIB, Paola Sangalli).*

Figure 2-10. *Stabilization technique. Construction on slope and in herringbone, in Bergara, Gipuzkoa (EFIB, Paola Sangalli).*

2.2.3 Mixed techniques

These techniques, unlike those mentioned above, combine the use of plant elements with materials such as wood, galvanized steel, stone, concrete, etc. In these techniques, the inert material acts as a stabilizer until the plants are able to perform this function (Figure 2-11, Figure 2-12, Figure 2-13, Figure 2-14, Figure 2-15, Figure 2-16 and Figure 2-17). These techniques include:

- Wooden framework
- Wooden steps
- Live trellises
- Reinforced earth or green walls
- Three-dimensional meshes, geocells, etc.
- Revegetated gabions/breakwater.

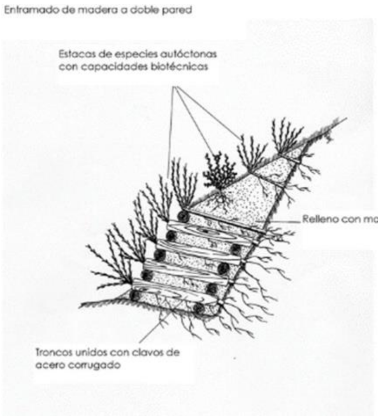

Figure 2-11. *Mixed technique. Wooden framework diagram (EFIB, Paola Sangalli).*

Figure 2-12. *Mixed technique. Wooden framework photo once vegetated (EFIB, Paola Sangalli).*

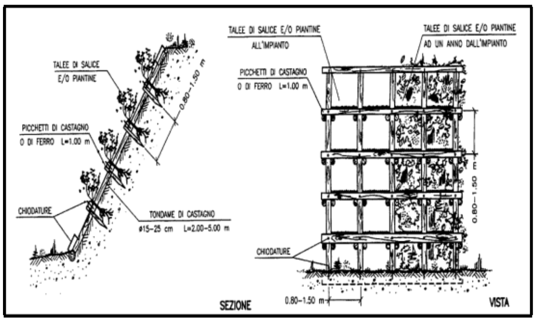

Figure 2-13. *Mixed technique. Diagram of section and elevation of a trellis (Source: Manual Regione Lazio) (EFIB, Paola Sangalli).*

Figure 2-14*. Mixed technique. Trellis in Leizaran and after one year (EFIB, Paola Sangalli).*

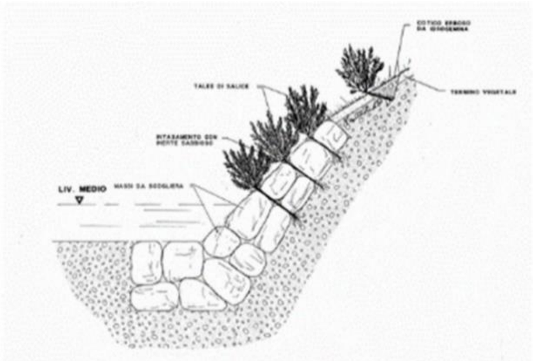

Figure 2-15. *Mixed technique. Diagram of revegetated breakwater (EFIB, Paola Sangalli).*

Figure 2-16. *Mixed technique. Photo of revegetated breakwater (EFIB, Paola Sangalli).*

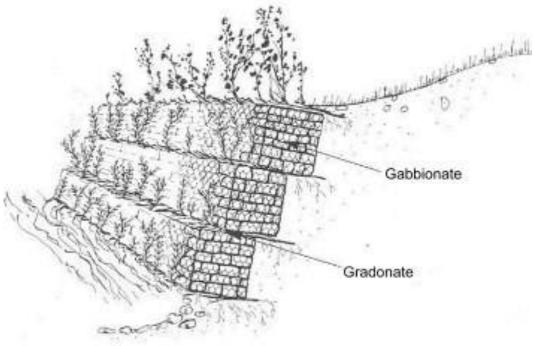

Figure 2-17. *Mixed technique. Diagram of revegetated gabion (EFIB, Paola Sangalli).*

2.2.4 Complementary techniques

Together with the construction techniques themselves, other techniques should be used to complement the previous ones, although they do not have the purpose of stabilizing or protecting against erosion (Figure 2-18). These include, for example, planting woody species to accelerate the development of vegetation, creating anti-noise barriers, drainage, fish ramps, etc.

The combination of one or more techniques makes it possible to obtain results that combine the technical aspects of stabilization with those of landscaping and ecology.

These techniques include, for example:

- Stone ramps: replace waterwheels
- Wood and stone dams: transverse elements in the riverbed that slow down the speed of the water
- Deflectors: longitudinal structures that direct the water flow.

Figure 2-18. *Complementary technique. Torrent dams and stone fish ramp (EFIB, Paola Sangalli).*

These techniques have a series of limitations that condition their execution, and they need to be taken into account:

- **Seasonality**. The work must be carried out when the plant material is at a suitable vegetative stage and when the local climatic characteristics are favourable to the adequate rooting of the vegetation. When using willow stakes, the intervention period will be during the vegetative stop, i.e. from November to February (in the Pyrenees), while for hydroseeding the most favourable period is spring.
- **Maintenance**. As the interventions do not have an immediate effect, checks and maintenance should be carried out after the intervention: thinning, replanting, plant replacement, fertilization, pruning, etc.
- **Trained personnel**. Given that these are recent techniques and that they should be applied simultaneously with other construction techniques, a major limitation is the lack of personnel trained in their use. Hence the importance of carrying out theoretical and practical training courses.
- **Obtaining the plant material to be used**. Often seeds of the most suitable species and varieties for the intervention are not available on the market, so standard seed mixtures are used, which are not always the most suitable. As for the procurement of willows, in many cases permission from the competent authorities is required to obtain them.
- **Safety conditions**. These techniques can replace traditional techniques only when the environmental and safety conditions guarantee their proper functioning. In other cases, in particular for reasons affecting life and health, it is preferable to resort to classical engineering techniques.

2.3 Some practical examples from the European Federation for Soil Bioengineering

The invited members of the European Federation for Biological Engineering (EFIB), Albert Sorolla and Klaus Peklo, presented practical examples of bioengineering applications during the training day. These techniques were aimed at stabilizing slopes in rural and urban contexts.

Albert Sorolla from the Spanish Association of Landscape Engineering (AEIP; *Asociación Española de Ingeniería del Paisaje*) presented examples of interventions carried out in the Catalonian Pyrenees, mainly aimed at slope stability and the restoration of vegetation cover (Figure 2-19). Other examples were for the restoration of river banks. From his experience, Albert Sorolla (AEIP) indicated the main advantages and possibilities offered by these techniques compared to traditional ones. He presented a number of examples from his twenty-five years' experience in this field.

Figure 2-19. *Example of vegetation cover restoration in the Catalonian Pyrenees (Albert Sorolla, AEIP).*

Klaus Peklo from the European Federation for Biological Engineering (EFIB) presented his work, mainly focused on the fluvial field (Figure 2-20). In many cases the solutions are mixed, combining the use of bioengineering techniques with traditional engineering ones. Klaus Peklo presented interventions located in the middle and lower reaches of rivers flowing down from the Pyrenees, in which flooding caused problems in urban areas.

Figure 2-20. *Example of fluvial slope stabilization in an urban area (Klaus Peklo, EFIB).*

3 Learning from PHUSICOS in the Pyrenees

This chapter 3 includes the elements presented on the second day of the event during the results seminar, aimed at supporting the reflections on the technical aspects of implementing NBS to deal with natural hazards (subchapter 3.1) as well as the participatory process that accompanied the implementation of NBS at the four Pyrenean sites (subchapter 3.2).

3.1 Work done by PHUSICOS at the Pyrenees sites and main lessons learned

This subchapter picks up the elements to present the work carried out by PHUSICOS at the four Pyrenean sites in order to lay the foundations for further reflection on NBS application in dealing with natural hazards (subchapters 3.1.1, 3.1.2 and 3.1.3). These elements and the discussions that took place with the authorities and all the participants are summarized in subchapter **Feil! Fant ikke referansekilden.**. Furthermore, BRGM presented its work on rock fall modelling carried out in Artouste to demonstrate the technology used and the main results of this work (sub-chapter **Feil! Fant ikke referansekilden.**).

3.1.1 Natural hazards in the Pyrenees and their specificities

Mountain areas, and in particular the Pyrenees, are specific territories that combine a great diversity of adverse events, earth movements (from rockfalls to large landslides), earthquakes, avalanches, torrential floods, storms, together with the small size of developed areas. Urban areas are limited in size and road networks present strong systemic vulnerabilities because the alternatives offered are few and far between.

Given these two characteristics, the risks are often high and their management can be complex and costly. Another important characteristic of mountainous territories lies in the importance of sites exposed to several hazards and in the percentage of exposed areas. Very few areas are risk-free, so the prevalence and importance of risks in mountain areas raises the crucial question of the prioritization of areas to be protected and the solutions to be provided in terms of risk reduction and land management. This prioritization is inevitable for two reasons: financial and technical. Even if technical capacities would allow us to protect everything today, the financial resources to be mobilized -particularly public funds- would be disproportionate to what is at stake. The second reason is technical. Despite current technological capacities, it is not possible to protect all the territories. Moreover, the political demand for risk prevention is relatively recent, in the face of development and urbanization processes.

Thus, several fundamental questions arise in terms of risk management and reduction, especially in mountainous areas and particularly in the Pyrenees:

- **What level of risk can be accepted at the territorial level?** This question is important and raises the crucial issue of ‘acceptable level of risk’. It is all the more important as the answer to this question conditions the technical solutions to be implemented and the financial resources to be mobilized.
- As a corollary to this first question, there is the **question of prioritizing the areas to be protected and the solutions to be provided**, knowing that we cannot protect everything.
- As a corollary to these first two questions, there is also the question of the responsibility of mayors in their respective territories. **How to limit the responsibility of mayors and help them in the reasonable, balanced and sustainable management of their territory? How can we help them to deal**

with the often-paradoxical demands of their constituents, who want to be protected and live freely without excessive constraints?

- Even if we are able to protect certain sectors, **how can we find a reasonable balance between the protection of territories and their development?** Do 'reasonable' balances always exist in view of the divergent and sometimes opposing interests that arise in the territories?
- **How to propose integrated solutions that respond to several concomitant protection (multi-hazard approach) and development issues, in order to optimize solutions and investments?**
- **How can we define optimal solutions that integrate both climate change and territorial transformation?**
- **How to define solutions that integrate environmental protection and territorial development in a balanced way?** How to protect without 'paralysing' the territories? How to find a balance between sanctuary and economic and social development?
- **How can we best involve all the stakeholders in the territory, and in particular the resident population, with good intentions but also with realism?**

3.1.2 Study sites in the Pyrenees and the basic principles of NBS

The four Pyrenean sites of the PHUSICOS project (Figure 3-1) addressed the following hazards:

- Capet Forest site: snow avalanches.
- Artouste site: rock falls.
- Santa Elena site: erosion and rock falls.
- Erill la Vall site: erosion and debris flows.

Figure 3-1. *Location of the Pyrenean sites on the French and Spanish sides of the border (Source: in-house with image from Google Earth).*

The objective of the PHUSICOS project was to determine and validate whether nature-based solutions (NBS) could provide effective and appropriate answers to disaster risk reduction and reduction, by integrating all the issues outlined above as an alternative to conventional engineering solutions.

The aim was to design and implement solutions:

- based on nature
- effective in reducing risk
- involving local and regional stakeholders
- promoting local economic development
- as alternatives to the 'grey' solutions of classical engineering.

In order to carry out this project at each of the four sites, an overall and comprehensive methodology was put in place: varied contexts and risks calling for adapted solutions, engagement of multiple stakeholders, operational and pragmatic responses that go beyond theoretical foundations. The definition of relevant and adequate solutions had to integrate the risk management issues (subchapter 3.1.1) but also fully understand the level of risk to which the sites were exposed. Good decision-making in terms of balanced risk management requires both an understanding of all the components of risk and a thorough knowledge of the territory and the hazards.

The PHUSICOS experience has highlighted the difficulty involved in obtaining or accessing the basic data necessary for in-depth knowledge of the risks, characterization of each site and hazards. Processing this data is both costly and time consuming, so these constraints have led stakeholders to resort to innovative techniques that ensure the definition and implementation of operational solutions and guarantee the responsibility of the authorities in charge of risk management, primarily mayors.

In addition, the operational implementation of nature-based solutions, the feedback from PHUSICOS specific to bioengineering, as well as the reflections shared with all stakeholders led people to challenge the definition of nature-based solutions, according to IUCN (subchapter **Feil! Fant ikke referansekilden.**).

3.1.3 Methodology and considerations regarding NBS implementation for natural hazard reduction

The general approach to defining and sizing nature-based solutions to reduce natural hazards is based on the following steps:

1. Identification of the natural hazards considered
2. Risk assessment and prioritization of risk areas
3. Determination of the geographical zones where NBS will be implemented and initial assessments
4. Design and sizing of NBS
5. Validation of the selected NBS
6. Operational implementation of NBS in the field
7. Feedback on the implementation of NBS
8. Definition of a management and monitoring framework for NBS
9. Definition of a communication framework

The following table (Table 3-1) describes each of the steps:

Steps	Considerations
1. Identification of the type of natural hazard considered	In PHUSICOS, four sites in the Pyrenees were selected with the following hazards: ▪ Capet Forest site: snow avalanches. ▪ Artouste site: rock falls. ▪ Santa Elena site: erosion and rock falls. ▪ Erill la Vall site: erosion and debris flows.
2. Risk assessment	Wherever possible, the risk assessment should be quantitative. It must be able to define, in a quantified way, the return periods associated with potential losses. These losses are traditionally measured in terms of human victims (deaths, injuries), damage, destruction, loss of function or activity, and/or economic losses, whether these losses are direct or indirect.
2.1 Hazard	The hazard aims at defining the intensities of the natural events for given return periods. It requires an understanding of the physical mechanisms involved and determining the parameters involved in these mechanisms.
2.1.1 Acquisition of basic data	The acquisition of baseline data is the key to good risk quantification. It is thus necessary to have tools that allow the rapid acquisition of very precise data at a reasonable cost.

Steps	Considerations
	Authorities have difficulty investing in master data acquisition campaigns, partly because the cost is high but also because they lack the tools and skills to store and share information. The implementation of innovative tools for acquisition, information feedback and efficient sharing are priorities in the management of risks and territories.
2.1.2 Modelling	Hazard modelling is an important step in decision making; it is a tool that allows to simulate what is likely to happen in the field and to access parameters for the design of protective works. Models are only partial images of reality and must be based and calibrated on reliable and exhaustive data from field campaigns. Technicians and scientists must be able to clearly communicate the limits of the models and the uncertainties associated with them to politicians; also, because the responsibility of politicians is engaged. Modelling is a major asset for simulating different scenarios. At least two scenarios should be set up: a first scenario to assess the level of hazard before the implementation of NBS (initial assessment) and a second scenario integrating NBS. The difference between the two scenarios will quantify the risk reduction and determine the residual risk. NBS will thereby be validated, considering that the residual risk is acceptable.
2.2 Assets and exposure	The analysis of the assets and their exposure to hazards, as well as the definition of their vulnerability, define the risk. In many cases, these two components are only approached in a very general way because they are not impacted by NBS. In other words, the exposure and vulnerability of the assets are not impacted by NBS. The variations in risk are only attributable to variations in the hazards on which NBS have an impact. The inventory and the analysis of the assets (exposure - probability of presence) allow us to prioritize the zones at risk and to determine the zones where NBS are the most appropriate. The nature and the exposure of the assets allow decisions to be made on the acceptability of the risk, the need to implement risk reduction solutions, and the usefulness of applying NBS. Data on assets must be collected and stored at local government level. This is an area where many local governments are failing.
2.3 Vulnerability	The vulnerability assessment of the assets involves data that are not easily accessible. The analysis of vulnerability (physical and systemic) opens up a range of possible actions in terms of risk reduction.
2.4 Prioritization of risk areas	The prioritization of risk areas can be based either on the results of modelling or on the feedback of the damage suffered. It must allow to decide on: ▪ Whether or not risk reduction solutions are needed. ▪ The relevance of using NBS.
3. Determination of the geographical zones where NBS will be implemented and first assessments	The determination of the areas where NBS can be implemented is based on: ▪ Prioritization of risk zones (not everything can be protected, especially in mountain areas). ▪ The financial resources to be mobilized according to the level of risk. ▪ The financial resources available. ▪ The existence (or not) of a regulatory framework on the need to implement actions. ▪ The existence (or not) of a normative framework on the solutions to be put in place to reduce or even eliminate the liability of mayors, authorities or managers in the event of damage. It is worth mentioning that in many cases, ‘reasonably necessary’ is not defined, and that it is often judged *a posteriori*.

Steps	Considerations
	The appropriateness and relevance of implementing NBS must be part of a global approach to space management and a complementary approach with grey solutions, including taking temporal aspects into account. It may be advisable to set up a general protection plan, structured in both geographical and temporal phases. This will include: ▪ Identifying the zones where NBS will bring significant results (hazard intensities and effective possibilities to reduce the frequency and/or intensity of the hazards). ▪ Identifying the types of NBS that are adapted, in principle, to the hazard faced. ▪ Defining a set of basic indicators that will be monitored (risk reduction; technical feasibility; impact on the environment and ecosystem; impact on society; impact on the local economy). ▪ Carrying out the initial assessment at each site.
4. Design and sizing of NBS	This step must be conducted within the framework of exchanges between scientists, technicians and local communities to mobilize potential local resources and local skills to strengthen local economic development. It is important to use local materials for the implementation of NBS, to reduce the carbon footprint of long-distance transportation. Local materials should define the design and sizing of NBS, not the reverse. The design and dimensioning of NBS is an engineering task and must be carried out by structures with recognized skills. They must not only be based on a strong theoretical framework, but also on laboratory or onsite tests, scale models or full-scale prototypes.
5. Validation of NBS	To date, there is no normative framework for the development and implementation of NBS. The validation of the solutions can be theoretical, by calculation, or experimental. This validation must be carried out by persons and/or structures with recognized competences.
6. Operational implementation of NBS in the field	The implementation of NBS must be done in compliance with the technical specifications. Contracting authorities should strive to design 'realistic' specifications that are responsive to local constraints. Such specifications will also ensure that firms are not deterred from bidding. The project owner and the project manager must ensure -at an early stage- that administrative constraints are lifted. The setting up of working groups with all the stakeholders could be useful to avoid possible blockages. Local companies should be encouraged to respond to calls for tender or join groups that respond. This will not only promote local economic development, in many cases will facilitate subsequent maintenance interventions.
7. Feedback on the implementation of NBS	This includes: ▪ Carrying out complete feedback on the implementation of NBS (technical, financial, administrative and planning aspects) by involving all the stakeholders. ▪ Identifying deviations and changes from initial objectives and measuring (quantifying) the impacts. ▪ Making all the data acquired available within the existing tools of the local authorities and dedicated NBS platforms.
8. Definition of a management and monitoring framework for NBS	This framework for managing and monitoring NBS will need to determine: ▪ The frequency and modalities of monitoring of the works. ▪ The criteria and modalities of maintenance of the works.

Steps	Considerations
	▪ The criteria and procedures for the removal of NBS structures if they are found to be unnecessary or deficient, or if they are likely to increase risk or degrade the environment. ▪ The definition of the responsibilities and obligations of each of the stakeholders (communities, State organisms, public organizations, technicians, companies). ▪ Updates to assessment indicators (risk reduction; technical feasibility; impact on the environment and ecosystem; impact on society; impact on the local economy), defining the frequencies and stakeholders to be mobilized as well as the actions to be taken in the event of a negative evolution.
9. Definition of a communication framework	This communication framework is to be put in place from the beginning of NBS implementation and is cross-cutting to all the above steps. It is necessary to make all stakeholders understand what is at stake with NBS and their interests, limitations and constraints. This includes explaining the concepts of risk and the balance to be struck between protection, development and costs. All available media should be mobilized to promote NBS (documents, videos, websites, applications, field visits, workshops, conferences, living labs, seminars).

Table 3-1. *Considerations at each step of the methodology for the implementation of NBS for natural hazard reduction.*

The tables and figures below present the main results of the general methodology applied at each of the four sites:

- Artouste (Table 3-2 and Figure 3-2).
- Capet (Table 3-3 and Figure 3-3).
- Santa Elena (Table 3-4 and Figure 3-4).
- Erill la Vall (Table 3-5 and Figure 3-5).

Tâches / travail réalisé	Domaines							Intérêt particulier	
ARTOUSTE Capture d'écran	Données de base	Modélisation	Travaux	Surveillance	Gestion	Communication			Innovation
• Lidar aérien	x						A1	Utilisé pour la modélisation des forêts et des chutes de blocs. Nouvelles méthodologies pour la spatialisation à l'échelle du versant des données de modélisations : types d'arbre, positions des arbres, diamètres des troncs, zones de départ, nature des sols et rugosité du sol	***
• Lidar terrestre autoportable	x						A2	Inventaire des arbres (localisation, diamètre)	***
• Dendrochronologie	x						A3	Modélisation chutes de blocs (hauteur max d'impact)	**
• Inventaires des zones instables	x						A4	Caractérisation précise des blocs instables	*
• Modélisation théorique des NBS		x					A5	Différentes configurations	***
• Site expérimental avec bélier		x					A6	Site unique pour l'expérimentation de la résistance des structures	***
• Site expérimental in situ		x					A7	Expérimentation de la résistance des structures et de la forêt	***
• Mise en place des NBS et déplacement de blocs			x				A8	Actif, passif – différents designs - exhaustif	**
• Modélisation de la forêt		x					A9	Méthodologie innovante	**
• Modélisation des chutes de blocs		x					A10	Méthodologie innovante (zones de départ)	*
• Living Lab (TUM)						x	A11	Interaction avec les élus	
• Mise en place d'un comité technique					x		A12	Phusicos – Parc – Municipalité de Laruns	
• Protocole de propriété, suivi, maintenance				x	x		A13	Phusicos – Parc – Municipalité de Laruns	
• Séminaire de restitution						x	A14	Technicien et décideurs	

Table 3-2. *Main activities for the implementation of NBS at the Artouste site and the particular interest of each of them, evaluated on a scale of degree of innovation (in French). This table was presented on the second day of the event as an input for reflection with the authorities and participants.*

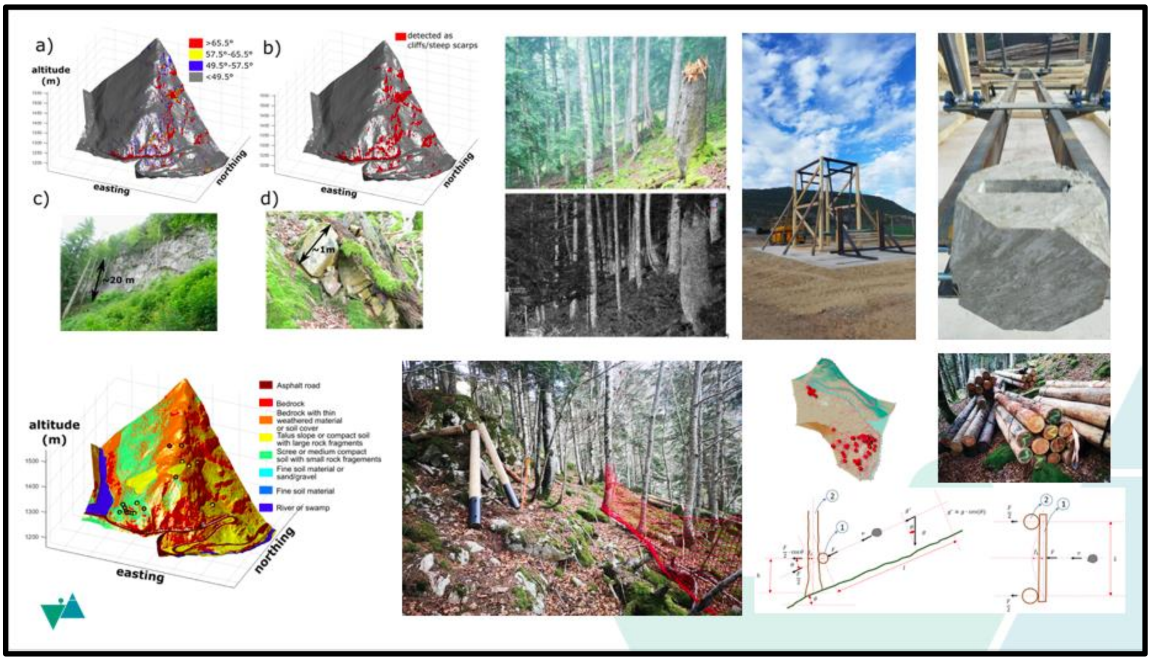

Figure 3-2. *Illustrations of the modelling analysis, theoretical design of NBS, implemented NBS and installations for testing NBS for the Artouste site (in French).*

Tâches / travail réalisé	Domaines							Intérêt particulier	
CAPET	Données de base	Modélisation	Travaux	Surveillance	Gestion	Communication			Innovation
• Lidar aérien estival (préalable au projet)	x						C1	Utilisé pour cartographie IMA, cartographie des ouvrages de génie civil existants et cartographie des zones à traiter dans le cadre du projet	
• Calcul automatisé de l'Indice de Maîtrise de l'Aléa par la forêt (préalable au projet)	x	x					C2	Identification des secteurs où la forêt ne joue aucun rôle de stabilisation du manteau neigeux	
• Analyse des essences adaptées et acceptables, en lien avec comité technique (PNP, CBNP, DSF, ONF)	x					x	C3	Dans contexte de changement climatique et d'apparition de pathogènes, trouver des alternatives au pin à crochets	**
• Identification des zones à planter selon topographie, existence d'ouvrages de génie civil	x		x				C4	Identification des zones à planter avec ou sans tripodes	
• Travail du sol pour planter en collectif			x				C5	Meilleure reprise	
• Mise en place des tripodes			x				C6	Protection des plantations / bois local. Amélioration à court terme de la stabilisation du manteau neigeux, réduction des actions sur les ouvrages de génie civil	***
• Plantation des collectifs			x				C7	Amélioration à moyen terme de la stabilisation du manteau neigeux, réduction des actions sur les ouvrages de génie civil	
• Living Lab						x	C8	Réunion avec les élus, réunion publique	
• LIDAR aérien hivernal	x						C9	Pour comparer avec LIDAR estival et mieux cerner les zones d'accumulation de neige -> zones à traiter pour risque de départ d'avalanche, mais plus défavorable pour la végétation	

Table 3-3. *Main activities for the implementation of NBS at the Capet Forest site and the particular interest of each of them, evaluated on a scale of degree of innovation (in French). This table was presented on the second day of the event as an input for reflection with the authorities and participants.*

Figure 3-3. *Illustrations of the Capet Forest site and NBS implemented by PHUSICOS (wooden tripods and afforestation). At the bottom left of the figure, grey infrastructure can be seen on the slope with the village of Barèges at the bottom.*

Tâches / travail réalisé	Domaines							Intérêt particulier	
Capture d'écran **SANTA ELENA**	Données de base	Modélisation	Travaux	Surveillance	Gestion	Communication			Innovation
• Reference ancienne travaux RHF (=travaux RTM). Arratiecho.1904	x						S1		
• Modélisation des ouvrages		x					S2		
• Tests expérimentaux des ouvrages		x					S3		
• Mise en place d'une surveillance vidéo en continue				x			S4		
• Mise en place des terrasses			x				S5		
• Mise en place de végétation autochtone			x				S6		
• Visites étudiants						x	S7		
• Lidar terrestre fixe	x						S8		
• Comparaison évolution avec talus morainique proche sans traitement							S9		

Table 3-4. *Main activities for the implementation of NBS at the Santa Elena site (in French). This table was presented on the second day of the event as an input for reflections with the authorities and participants.*

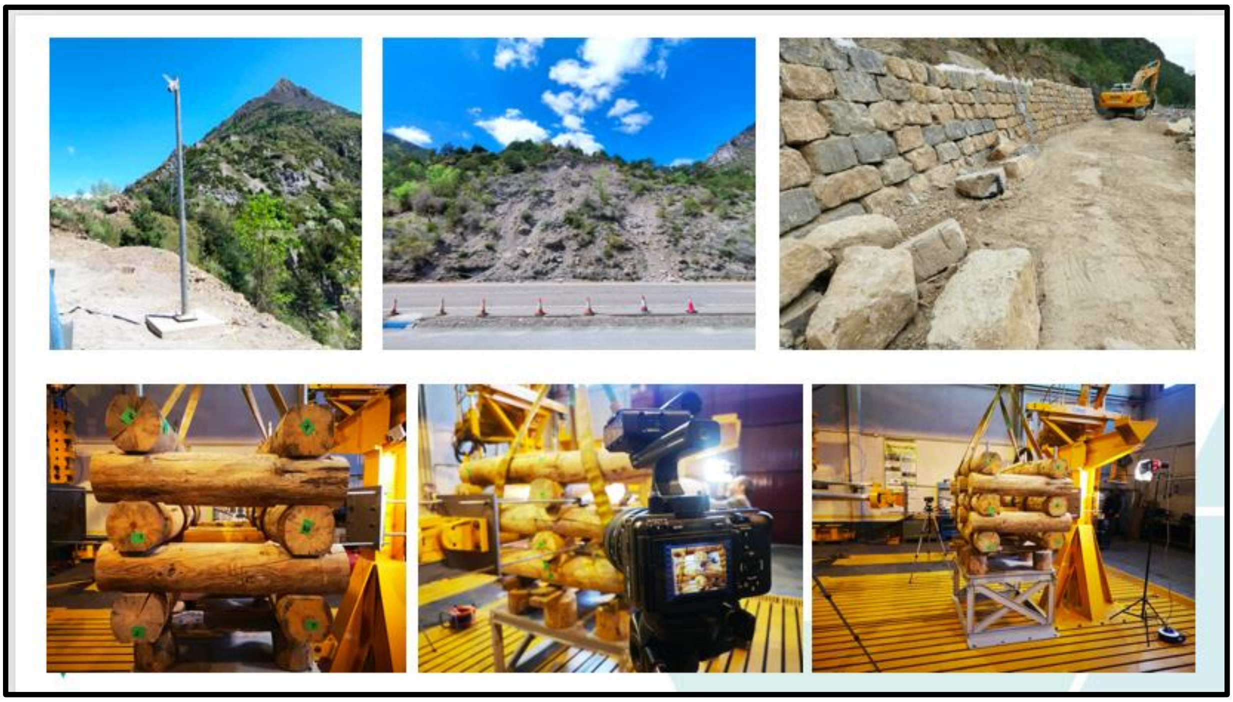

Figure 3-4. Illustrations of NBS implementation at the Santa Elena site and testing the structure resistance in the laboratory.

Tâches / travail réalisé	Domaines							Intérêt particulier	
Erill	Données de base	Modélisation	Travaux	Surveillance	Gestion	Communication			Innovation
• Laboratoire EARLY WARNING	x						E1	2009-2023	
○ Dashboard remote control - thresholds	x						E2		
○ Station météo	x						E3		
○ 5 piézomètres même vertical	x						E4		
○ Flowmeter (Q)	x						E5		
○ Géophones (4)	x						E6		
○ VX160 H6 System + Loadcells	x						E7		
○ Camera photo	x						E8		
○ Time laps camera	x						E9		
• Lidar aérien	x						E10	Utilisé pour la modélisation des forêts et des chutes de blocs	
• Lidar terrestre	x						E11	Inventaire des arbres (localisation, diamètre), modélisation chutes de blocs	
• Stratigraphie historique	x						E12	Modélisation aire occupation, hauteur max et pressions d'impact	
• Inventaires des zones actuellement actives instables	x						E13	Caractérisation précise des zones actives instables	
• Control volumétriques des déplacement et transport dans le basin							E14		
• Modélisation théorique avant et après des NBS		x					E15	Différentes configurations et période de return	
• Site expérimental in situ		x					E15	Expérimentation de la résistance des structures et de la forêt	
• Mise en place des NBS et déplacement de blocs			x				E17	Actif, passif – différents designs - exhaustif	
• Modélisation des flues		x					E18	Zones de départ, trajectoire et arrêt	
• Living Lab						x	E19	Interaction civil et technique	
• Protocole de propriété, suivi, maintenance					x		E20	Phusicos – Parc – Municipalité de Laruns	
• Séminaire de restitution						x	E21	Technicien et décideurs	

***Table 3-5.** Main activities for the implementation of NBS at the Erill la Vall site and the particular interest of each of them (in French). This table was presented on the second day of the event as an input for reflections with the authorities and participants.*

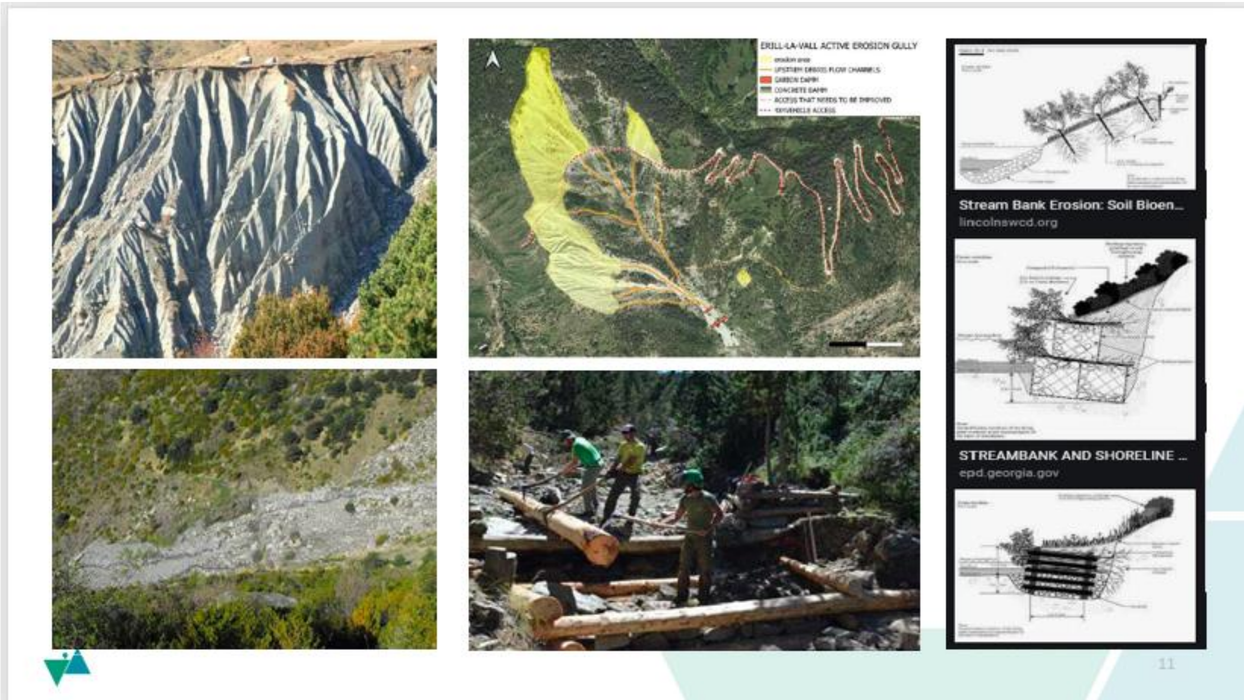

Figure 3-5. *Illustrations of NBS implementation at the Erill la Vall site and the design of krainer walls.*

3.1.4 Summary of the experience of NBS implementation at the four Pyrenean sites as an input for overall learning on NBS for natural hazard reduction in mountain areas

NBS in the Pyrenees large-scale demonstrator site: numerous innovations that make an impact

The NBS that have been implemented in the Pyrenean sites have been developed through the application of several advances and innovations, notably:

- The use of Lidar techniques (terrestrial - drone - airborne) in the Artouste, Erill la Vall and Capet Forest sites; these tools provide unequalled quality of data, with the possibility of realizing digital terrain models even in sectors where vegetation is abundant, which was not the case with the techniques based on ortho-photographs.
- Innovative modelling has been implemented, on one hand to model the forest in detail (type of trees, location and diameter of trunks from test areas validated in situ and surface models of terrain developed from Lidar data), and on the other for the modelling of rock falls at the Artouste site.
- Carrying out laboratory tests to validate NBS implemented at the Santa Elena site.
- Setting up a full-scale test platform within the timber company EIFORSA to test and validate NBS implemented at the Artouste site. Its maintenance and

perpetuation are a key element in carrying out other tests and, if necessary, setting up protocols for the standardization and normalization of NBS.

- Setting up a full-scale experimental site in the commune of Laruns (on a site called Gourzy) with the support of the mayor and members of the municipal council. Such sites are rare; they must be perpetuated (identification of funding sources, implementation of a communication campaign to inform future projects and stakeholders who need testing of NBS to reduce the risks from rock falls).
- Design, testing and validation of active and passive NBS to reduce rock falls, coupled with the use of forestry resources as a natural preventive solution. NBS have also been developed in line with bioengineering practices to stabilize slopes exposed to erosion risks (especially in glacial till deposits (Santa Elena site), and in highly impacted watersheds (Erill la Vall site)).

NBS, alternatives or complementarity with grey solutions

At the end of PHUSICOS, the perception of NBS and their role has changed. If these solutions were largely considered as alternatives to grey solutions, the feedback of experience in mountain sites -and in particular for the problems related to rock falls, erosion, and shallow landslides)- now puts them on a complementary footing with grey engineering solutions. This complementarity is manifested at the Artouste site, where a sector with ‘grey’ measures has been installed in which high energy levels are expected and NBS where energies are lower. This complementarity can also be seen at the scale of a structure with mixed achievements (particular case of the Santa Elena site).

NBS cannot be implemented where energies mobilized are high. However, the limits of use cannot be defined in a generic way; they must be defined and validated on a case-by-case basis, depending on the hazard to be addressed and the materials available for the design of solutions. Hence, NBS must be designed, dimensioned and implemented in a multidisciplinary engineering framework. The spectrum of situations for which NBS can be used is, however, wide, but it remains to be defined, standardized and normalized. Experimental installations such as those at EIFORSA and experimental sites such as Gourzy are particularly interesting tools for defining the limits and the most suitable solutions.

NBS, Nature-based Solutions

Like the role of NBS in the spectrum of possible solutions to reduce risks, the approach implemented by PHUSICOS in the Pyrenees has evolved towards pragmatic hybrid solutions. Feedback from bioengineering during the training day has also contributed to a broader perception among many partners. The terraces set up in Santa Elena illustrate this evolution. The basic structures put in place are mostly a hybrid solution rather than a NBS in the strictest sense. As with the grey solutions, the structures implemented serve to support the implementation of plant systems. However, in contrast to grey solutions, the NBS put in place will be progressively and, in many cases, quickly swallowed up by the natural vegetation and the basic structures will decompose until they disappear. This is not the case with grey solutions. NBS can therefore be defined in a broader time frame. Bioengineering feedback shows that in a few years (sometimes only 2 or 3 years), nature totally takes over the initial base structures that are designed as facilitators.

NBS, how effective are they in reducing risks

We should remember that NBS developed and implemented in the Pyrenees were aimed exclusively at reducing hazards, and in no case at reducing the vulnerability or exposure of elements at risk. This is shown by the modelling of rock falls for the Artouste site. The effectiveness of NBS is a reality as long as they are used appropriately. If NBS are relevant to reduce the rock falls hazard in contexts where the initial level of hazard is 'moderate', these solutions do not necessarily provide a satisfactory answer in high energy contexts. Indeed, the usefulness of NBS depends totally on their design. It is undeniable that feedback and experimentation will open up new opportunities and validate these solutions for new areas that are not accessible today. Just like grey solutions, NBS will evolve, and their spectrum of positive response with it.

A particularly important point must also be emphasized regarding their effectiveness. NBS become stronger over time with a risk reduction benefit, but also an economic benefit. NBS are mostly self-regulating and self-maintaining, while the cost of maintenance generally increases for grey engineered solutions. Therefore, NBS represent solutions whose efficiency increases gradually and naturally over time, and whose maintenance costs decrease or even disappear.

NBS, fostering local economic development

This is another strong argument for the promotion and development of NBS. The concern is legitimate, and it has been widely supported by the Mayor of Laruns. The village has considerable forestry resources, so the mayor of Laruns asked that NBS be designed and implemented with local resources and involving local companies as much as possible. This point is particularly important in the overall strategy for designing NBS in that it imposes specific boundary conditions on scientists, technicians and companies. It is not a matter of identifying resources that meet a given design but of reversing the constraint logic by imposing resources that exist locally on the designer, with their own characteristics, and which may be not as good as those usually required. It is up to the designer to define solutions with what is provided. This practice is new and may seem somewhat esoteric, but it is full of meaning, perspectives and innovation. It will certainly complicate, possibly delay or even make standardization impossible, but it will force scientists, authorities and standardization bodies to change their paradigm. The input parameters of the models and standards will be different, but they will lead to more pragmatism, more customization, reduction of the carbon footprint, strengthening of local economies, and consequently increasing the acceptance of NBS.

3.1.5 Modelling: interest and limits. Example of the modelling of rock falls at the Artouste site

The modelling of hazards is essential to know levels of risk and define appropriate solutions for risk reduction. It is complex because it involves integrating multiple parameters that are sometimes difficult to obtain, and whose spatial variabilities are different. The modelling of rock falls conducted on the Artouste site by BRGM and the University of Naples (UNINA) illustrates both the interest of these models, the difficulty of accessing certain parameters, the need to make certain modifications, the limitations of the results and the impact on the responsibility of the people in charge of the safety of the population, particularly mayors.

More details on hazard modelling can be found in D4.4 '*Modelling changing patterns of hazard and risk and identifying the return period of the extreme events that* NBS *could safely withstand*'.

While the modelling was conducted on a relatively large sector, the implementation of NBS (Figure 3-6) was concentrated on a sector with a moderate risk level. On the sector for which the level of hazard was the highest, a solution based on metal nets was preferred by the mayor of the municipality in view of the need for protection, the responsibility involved and the history of accidents that had occurred on departmental road 934 (subchapter 1.2.2). This decision by the mayor has been supported by the results of rockfall runout modelling.

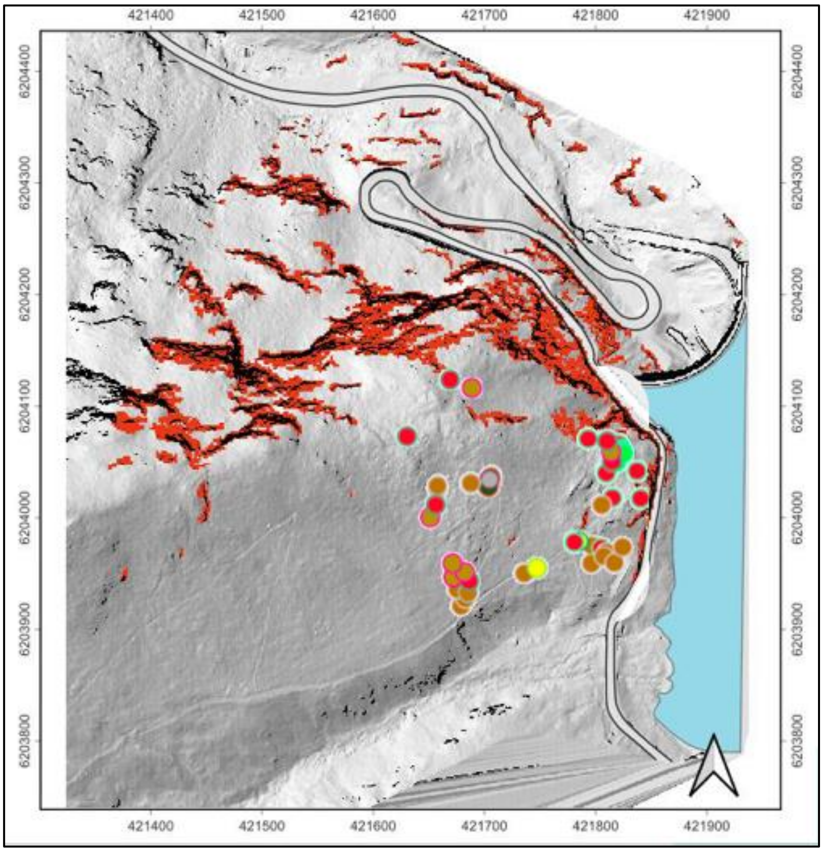

Figure 3-6. *Layout of the different types of NBS structures (round).*

Modelling using innovative technologies and methods

The modelling was done using airborne LIDAR data, which allowed for a digital terrain model with a resolution of 25 cm. The ROCKYFOR3D model (Dorren *et al.*, 2012) was used, with the following data:

- Digital terrain model, testing different resolutions.
- The starting zones of the blocks, determined by processing of the digital terrain model and a field campaign.
- Different block shapes based on field investigations.
- Soil roughness from field investigations and digital terrain model processing.
- Soil type maps based on field work and digital terrain model analysis.
- Forest (exhaustive location of trees, tree type and tree diameter over a limited area from terrestrial Lidar imagery), combined with canopy modelling over the entire study site to extrapolate the data acquired in the test area.

The acquisition of basic data with innovative tools (LIDAR), the processing of these data and the modelling carried out on the Artouste site have made it possible to highlight totally different levels of risk between the northern and southern zones (Figure 3-7), with a much higher level of risk in the northern zone (greater energy and rebound height).

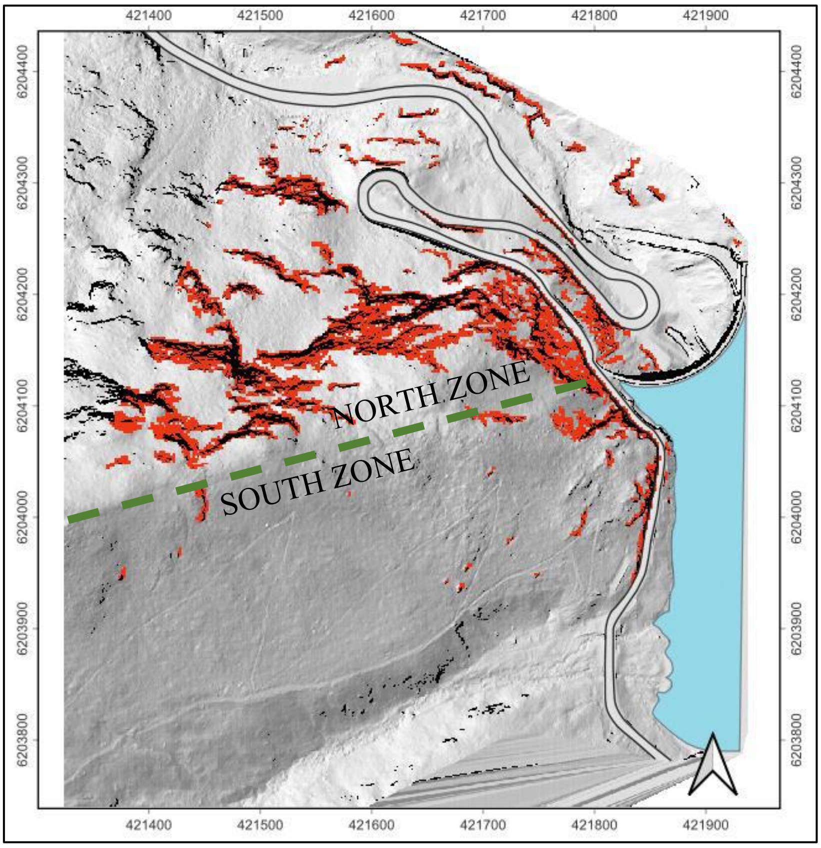

Figure 3-7. *Location of the release zones of the blocks (in red and black) in the North and South zones (source: BRGM).*

The results obtained validated:

- The mayor's choice of risk reduction solutions, with a grey engineering solution (metal nets to the north) and NBS to the south.
- The irrelevance of NBS alone with regard to the energies involved in the northern zone (they can, however, now be added as a complement to the nets, particularly as active solutions in the departure zones).
- The usefulness of NBS in the southern zone.

Even if the acquired data are extremely precise due to the use of airborne Lidar technologies, the modelling relies on a process defined on the basis of unit pixels, which means that the data are standardized (smoothed) on a given grid to proceed with the modelling, whether it is for slopes, soils, the presence of trees, the roughness of the soils, or the areas of release of blocks. This aggregation is necessary in relation to the calculation code, but it necessarily creates biases, even if these are limited by the field campaigns that allow the calibration of the basic parameters. Given current computational capabilities, R&D efforts must be made to develop block trajectory modelling software that is not based on raster models.

3.2 Learning from the Living Labs experience in the four sites of the large-scale demonstrator case of the Pyrenees

During the second day of the event, a mention of the participatory process, also called '*Living Labs*', has been made to highlight the results and share the main findings with the participants. This subchapter 3.2 picks up this content.

3.2.1 Approach developed during the Living Labs in the Pyrenees

Each of the four sites of the large-scale demonstrator case of the Pyrenees has had a strong involvement and engagement from multiple stakeholders, through the Living Lab processes.

The Living Labs are considered as a testbed and experimental and innovative environment where users are invited to discuss problems and co-create and co-design measures. They enable any individual, group and organization with an interest in nature-based interventions to follow the design, planning, implementation and evaluation process.

Stakeholder involvement has been structured throughout the project phases, seeking a particular engagement in each of the steps.

Phase 1. Study and project design

- Contribution from local knowledge.
- Participation in data collection.
- Critical review of the project design.

Phase 2. NBS implementation

- Providing local knowledge during the construction phase.
- Mobilizing local material.
- Involving local human resources.

Phase 3. During the construction and warranty period

- Involvement in monitoring.
- Involvement in the assessment of the efficiency of the measures.

3.2.2 Living Lab and other meeting activities at the Pyrenees sites

Many activities have been developed under the Living Lab concept. Table 3-6, Table 3-7, Table 3-8 and Table 3-9 describe the activities for each of the PHUSICOS intervention sites in the Pyrenees.

Date	Description of Living Lab and other meeting activities	Number or participants	Participant groups
11/09/2020	Field visit and meeting to introduce NBS and the planned sites for PHUSICOS in the Pyrenees	12	Decision makers, authorities, technical staff from local and departmental governments
17/11/2021	Technical meeting on progress across the demonstrator sites in the Pyrenees	10	Technical experts from each site, PHUSICOS partners in the Pyrenees
25/01/2022	Technical brainstorming on potential monitoring activities at the Pyrenees demonstrator case (part of the Consortium meeting extended to technical experts at the different Pyrenees sites)	11	Technical experts from each site, PHUSICOS partners in the Pyrenees
21/03/2022	Coordination meeting with involved stakeholders to present the assessment carried out by ONF-RTM and investment plan for Barèges and Sers protection; mention to PHUSICOS contribution to this plan: Technical assistance (ONF – RTM x 4), Municipal team (Mayor and Municipal Councillor x 2), Departmental Government (Departmental Sub-Prefect and Assistant x 2), Regional Development section (DDT x 1), Working Community of the Pyrenees – CTP – OPCC (x1)	10	Decision makers and authorities at local and departmental levels, technical staff from local and departmental governments
07-11/04/2022	Meeting with a demonstration and explanation of the Capet site to students from the SPRING SCHOOL in Lourdes, with ONF–RTM	14	Students, technical expert
13/04/2022	Meeting to collect comments and suggestions on the PHUSICOS platform on NBS, organised by BRGM (FR)	6	Technical staff from local and departmental governments
27/09/2022	Public information meeting (Living Lab) organised together with the Municipality and RTM–ONF – Presence of local residents and 3 Municipal authorities	9	Technical expert, local authorities and citizens
27/09/2022	In-depth interview (mid-round) – Mayor of Barèges	1	Authority
10-14/10/2022	Monitoring visit from NGI in the Pyrenees Field visit and meeting with the Mayors of Barèges and Sers, NGI Technical Experts, Technical Expert for Capet, invited expert from INRAE, Video reporter	8	Technical experts and Authorities
10/02/2023	Progress and latest steps at the Pyrenees sites	9	Technical experts from each site, participatory expert,

Date	Description of Living Lab and other meeting activities	Number or participants	Participant groups
	Technical coordination meeting with the PHUSICOS partners in the Pyrenees, Technical experts for each site and the Participatory Expert for Erill, Santa Elena and Artouste		PHUSICOS partners in the Pyrenees
11 & 12/04/2023	Training event and results seminar of PHUSICOS in the Pyrenees	26 (11/04) 32 (12/04)	Regional Authorities, authorities at local and departmental levels, technical staff from local and departmental governments, site technical experts, small and medium companies, NGOs and citizens

Table 3-6. *Living Lab and other meeting activities at the Capet Forest site, Municipalities of Barèges and Sers, Hautes-Pyrénées, France.*

Date	Description of Living Lab and other meeting activities	Number or participants	Participant Groups
11/09/2020	Field visit and meeting to introduce NBS and the planned sites for PHUSICOS in the Pyrenees	12	Decision makers, authorities, technical staff from local and departmental governments
Sept. 2020	In-depth interviews (5) from people concerned by interventions in Artouste, Santa Elena	5	Technical staff from local and departmental governments
15/04/2021	ARTOUSTE and SANTA ELENA – Formal introduction to NBS to local stakeholders	38	Decision makers, authorities, technical staff from local and departmental governments
15/10/2021	Living Lab (virtual) on the project design	14	Decision makers, authorities, technical staff from local and departmental governments, PHUSICOS partners in the Pyrenees
17/11/2021	Technical meeting on progress across the demonstrator sites in The Pyrenees	10	Technical experts from each site, PHUSICOS partners in the Pyrenees
25/01/2022	Technical brainstorming on potential monitoring activities at the Pyrenees demonstrator case (part of the Consortium meeting extended to technical experts from the different Pyrenees sites)	11	Technical experts from each site, PHUSICOS partners in the Pyrenees

Date	Description of Living Lab and other meeting activities	Number or participants	Participant Groups
07-11/04/2022	Meeting and field visit with students from SPRING SCHOOL to Laruns and Santa Elena, with EGCT Pirineos–Pyrénées	14	Students, technical expert
21/04/2022	Meeting aimed to capture comments and suggestions on PHUSICOS platform on NBS, developed by BRGM (ES)	9	Technical staff from local and departmental governments
22/04/2022	Field visit with master students from Polytechnical University of Madrid	20	Students, University professors, technical expert
27/07/2022	Field visit with students in vocational training on forestry nursery and landscape gardening in Canfranc	18	Young professionals on reconversion study/practice, technical expert
Sept. 2022	In-depth interviews	2	Technical staff and decision maker in local and departmental governments
10-14/10/2022	Monitoring visit from NGI in the Pyrenees Field visit to Santa Elena with NGI Technical Experts, Technical Expert for Santa Elena	5	Technical experts
10/02/2023	Progress and latest steps in the Pyrenees sites Technical coordination meeting with the PHUSICOS partners in the Pyrenees, Technical experts for each site and the Participatory Expert for Erill, Santa Elena and Artouste	9	Technical experts from each site, Participatory Expert, PHUSICOS partners in the Pyrenees
21/03/2023	Field visit and open-air meeting to see the progress of the works at Santa Elena together with the Mayor of Biescas, the Mayor of Laruns (Artouste site) and their municipal team, technical staff from local and departmental governments, PHUSICOS partners, Work company representatives involved in the works, Polytechnical University of Madrid, Technical and Participatory expert of the site, authorities and technicians from neighboring municipalities	19	Authorities at local and departmental levels, technical staff from local and departmental governments, site technical experts, small and medium companies, students
27/03/2023	Field visit with Regional, Province and Municipal Authorities (Regional Director for Road Management and Maintenance of Aragon Government)	14	Authorities at local and departmental levels, technical staff from local and departmental governments, site technical expert, small and medium company

Date	Description of Living Lab and other meeting activities	Number or participants	Participant Groups
11 & 12/04/2023	Training event and results seminar of PHUSICOS in the Pyrenees	26 (11/04) 32 (12/04)	Regional Authorities, authorities at local and departmental levels, technical staff from local and departmental governments, site technical experts, small and medium companies, NGOs and citizens

Table 3-7. *Living Lab and other meeting activities at the Santa Elena site, Municipality of Biescas, Aragon, Spain.*

Date	Description of Living Lab and other meeting activities	Number or participants	Participant Groups
11/09/2020	Field visit and meeting to introduce NBS and the planned sites for PHUSICOS in the Pyrenees	12	Decision makers, authorities, technical staff from local and departmental governments
Sept. 2020	In-depth interviews (5) from people concerned by interventions in Artouste, Santa Elena	5	Technical staff from local and departmental governments
15/04/2021	ARTOUSTE and SANTA ELENA – Formal introduction to NBS to local stakeholders	38	Decision makers, authorities, technical staff from local and departmental governments
09/09/2021	Coordination meeting for defining the project with the technical expert, municipal team, Pyrenees National Park, ONF and Departmental technical services	14	Decision makers, authorities, technical staff from local and departmental governments
15/10/2021	Technical meeting around Artouste site to gather thoughts on modelling exercises	10	Technical expert, University of Madrid members and partners, PHUSICOS partners in the Pyrenees
17/11/2021	Technical meeting on progress at the demonstrator sites in the Pyrenees	10	Technical experts from each site, PHUSICOS partners in the Pyrenees
19/11/2021	Coordination meeting to present the progress of the studies for the work in Artouste, the plan for the experimental lab and define joint calendar	13	Decision makers, authorities and technical staff from local departmental governments, technical expert and PHUSICOS partners in the Pyrenees

Date	Description of Living Lab and other meeting activities	Number or participants	Participant Groups
25/01/2022	Technical brainstorming on potential monitoring activities at the Pyrenees demonstrator case (part of Consortium meeting extended to technical experts in the different Pyrenees sites)	11	Technical experts from each site, PHUSICOS partners in the Pyrenees
07-11/04/2022	Meeting with municipal authorities and field visit with students from SPRING SCHOOL to Laruns and Santa Elena, with EGCT Pirineos – Pyrénées	14	Students, technical expert
13/04/2022	Meeting aimed to capture comments and suggestions on PHUSICOS platform on NBS, developed by BRGM (FR)	6	Technical staff from local and departmental governments
23/05/2022	Meeting with Pyrenees National Park. Start of negotiation on Artouste case with Pyrenees National Park managing staff, Managing staff of CTP, technical expert and R&D	9	Pyrenees National Park managing staff, technical expert and PHUSICOS partners in the Pyrenees
29/06/2022	Meeting with all stakeholders around Artouste, 7 stakeholders involved in this meeting after many bilateral efforts	15	Pyrenees National Park managing staff, technical expert, Decision makers, authorities, technical staff from local and departmental governments and PHUSICOS partners in the Pyrenees
June to September 2022	COORDINATION EXCHANGES for Collaboration protocol elaboration. Emails and exchange of calls to agree on protocol content and responsibilities	15	Pyrenees National Park managing staff, technical expert, decision makers, authorities, technical staff from local and departmental governments and PHUSICOS partners in the Pyrenees
21/09/2022	COORDINATION MEETING / TECHNICAL COMMITTEE 1st meeting. Presentation of work calendar for Artouste site and Lab site and work companies	9	Technical expert, Pyrenees National Park managing staff, local authorities and SME (company assigned to works in Artouste and hired technical supervisor)
Sept. 2022	In-depth interview	1	Responsible of Road maintenance for Pyrénées-Atlantiques Department
07/10/2022	Field visit to Artouste together with member of Scientific Council of Pyrenean National Park and Local authority	3	Technical expert, Pyrenees National Park scientific council member, local authority

Date	Description of Living Lab and other meeting activities	Number or participants	Participant Groups
10-14/10/2022	Monitoring visit from NGI in the Pyrenees Field visit to Artouste and meeting with Mayor of Laruns and municipal Team, NGI Technical Experts, Technical Expert for Artouste	8	Authorities and Technical experts
10/02/2023	Progress and last steps in the Pyrenees' sites Technical coordination meeting with the PHUSICOS partners in the Pyrenees, Technical experts for each site and the Participatory Expert for Erill, Santa Elena and Artouste	9	Technical experts from each site, Participatory Expert, PHUSICOS partners in the Pyrenees
20/02/2023	Technical Committee meeting (according to collaboration protocol signed for authorizing the works)	15	Members of the Technical Committee, compounded by representatives of Municipality of Laruns, Pyrenees National Park, Departmental Government of Pyrénées Atlantiques, RTM-ONF, ONF Pyrénées Atlantiques, GECT Pirineos-Pyrénées and CTP-OPCC
21/03/2023	Field visit and open-air meeting to see the progress of the works in Artouste and experimental site in La Peña, together with the Mayor of Laruns and his municipal team, technical staff from local and departmental governments, Pyrenees National Park representatives, PHUSICOS partners, company representatives involved in the works, Polytechnical University of Madrid, Technical and Participatory expert of the site, authorities and technicians from neighboring municipalities	19	Authorities at local and departmental levels, technical staff from local and departmental governments, Sites' Technical experts, small and medium company, students
03/04/2023	Field visit to Artouste together with member of Technical Committee members (according to collaboration protocol signed for authorizing the works)	5	Technical expert, RTM-ONF member, local authority, work companies' representatives involved in the works
11 & 12/04/2023	Training event and results seminar of PHUSICOS in the Pyrenees Visit to Artouste site as part of the Seminar	26 (11/04) 32 (12/04)	Regional Authorities, authorities at local and departmental levels, technical staff from local and departmental governments, site technical experts, small and medium companies, NGOs and citizens

Table 3-8. *Living Lab and other meeting activities at the Artouste site, Municipality of Laruns, Pyrénées Atlantiques, France.*

Date	Description of Living Lab and other meeting activities	Number or participants	Participant Groups
21/07/2021	Introduction to NBS and PHUSICOS project, visit to the site together with the Municipality team, regional and local stakeholders	16	Decision makers, authorities, technical staff from local and regional governments, technical expert
08/09/2021	Coordination meeting between involved stakeholders: Technical assistance, Municipal team, Regional Government of Catalunya (OCCC)	4	Decision makers, authorities, technical staff from local and regional governments, technical expert
10/09/2021	Living Lab (FtF) session with residents from the valley	27	Decision makers, authorities, technical staff from local and regional governments, citizens, technical expert
28/10/2021	Coordination meeting between involved stakeholders: Technical assistance, municipal team, Regional Government of Catalunya (OCCC)	6	Decision makers, authorities, technical staff from local and regional governments, technical expert
17/11/2021	Technical meeting on progress at the demonstrator sites in The Pyrenees	10	Technical experts from each site, PHUSICOS partners in the Pyrenees
25/11/2021	Coordination meeting between involved stakeholders: Technical assistance, Municipal team, Regional Government of Catalunya (OCCC)	5	Decision makers, authorities, technical staff from local and regional governments, technical expert
17/12/2021	Coordination meeting between involved stakeholders: Technical assistance, Municipal team, Regional Government of Catalunya (OCCC)	6	Decision makers, authorities, technical staff from local and regional governments, technical expert
17/12/2021	Living Lab with citizens to explain the context and contrast the proposed solution before its implementation	13	Decision makers, authorities, technical staff from local and regional governments, citizens, technical expert
25/01/2022	Technical brainstorming on potential monitoring activities at Pyrenees demonstrator case (part of Consortium meeting extended to technical experts in the different Pyrenees sites)	11	Technical experts from each site, PHUSICOS partners in the Pyrenees
04/03/2021	Coordination meeting between involved stakeholders: Technical assistance, Municipal team, Regional Government of Catalunya (OCCC)	6	Decision makers, authorities, technical staff from local and regional governments, technical expert

Date	Description of Living Lab and other meeting activities	Number or participants	Participant Groups
07-11/04/2022	Meeting with Municipality authorities and field visit with students from SPRING SCHOOL in Vall de Boí, with Kuroba4	14	Students, technical expert
21/04/2022	Meeting to collect comments and suggestions on the PHUSICOS platform on NBS, developed by BRGM (ES)	9	Technical staff from local and departmental governments
28/07/2022	Field visit and public informative session to civil society with authorities	13	Decision makers, authorities, technical staff from local and regional governments, citizens, technical expert
Sept. 2022	In-depth interviews	2	Authorities, technical staff from local and regional governments
10-14/10/2022	Monitoring visit from NGI in the Pyrenees Field visit to Erill with NGI Technical Experts, Technical Expert for Erill and Mayor of Vall de Boí	6	Technical experts
22/10/2022	Field visit and public informative session to civil society with authorities		Decision makers, authorities, technical staff from local and regional governments, citizens, technical expert
10/02/2023	Progress and last steps in the Pyrenees' sites Technical coordination meeting with the PHUSICOS partners in the Pyrenees, Technical experts for each site and the Participatory Expert for Erill, Santa Elena and Artouste	9	Technical experts from each site, Participatory Expert, PHUSICOS partners in the Pyrenees
23/03/2023	Coordination meeting between involved stakeholders: Technical assistance, Municipal team, Regional Government of Catalunya (OCCC)	6	Decision makers, authorities, technical staff from local and regional governments, technical expert
11 & 12/04/2023	Training event and Seminar of results of PHUSICOS in the Pyrenees	26 (11/04) 32 (12/04)	Regional Authorities, authorities at local and departmental levels, technical staff from local and departmental governments, Sites' Technical experts, small and medium companies, NGOs and citizens
22/04/2023	Living Lab with citizens and authorities to see and comment the final progress on the works		Decision makers, authorities, technical staff from local and regional governments, citizens, technical expert

Table 3-9*. Living Lab and other meeting activities at the Erill la Vall site, Municipality of Vall de Boí, Catalonia, Spain.*

3.2.3 Lessons learned from the Living Lab activities at the Pyrenees sites

The work done by PHUSICOS in the Pyrenees and the development of the Living Labs to support NBS implementation has brought key lessons learned and findings as following:

- The Living Labs bring knowledge to local populations and raise awareness around natural hazards and the corresponding risks present in an area.
- The Living Labs revalue local knowledge and give a voice to citizens and all interested stakeholders who take part in this participatory spaces and process. They give a new, innovative and technological perspective to ancient and traditional knowledge, often forgotten or neglected.
- In most of the Living Labs, a vague sensation of inability to influence or judge the work exists, delegating the technical expertise to hired specialists in charge of designing the solutions. This has been seen in the form of difficulties in mobilizing stakeholders and/or collecting opinions during the sessions. This confirms the need for a trust building process as a basis to exchange and debate the validity of the solutions, but also to ensure spaces for free exchange and respect of all opinions.

3.3 Co-benefits of NBS and soil monitoring: recommendations for Capet and Santa Elena sites

This subchapter 3.3 picks up a part of the elements presented during the second day of the event, particularly those focused on NBS co-benefits. The part focused on soil monitoring indicators and recommendations aimed at the Capet Forest and Santa Elena sites constitute a commitment from CREAF to restitute the soil analysis results and main findings for the updating of the RTM-ONF soil monitoring protocols. The aim of including them in its report is to make them available to any forest technician who is interested in applying NBS and monitoring the benefits on carbon sequestration and other ecosystem services. Along this subchapter, references and recommendations are tailored to the NBS implemented at Capet Forest and Santa Elena sites. Nevertheless, most of the indicators and corresponding procedures can be applied to other sites intervened by NBS.

NBS set out to mitigate the risk posed by landslides, rockfalls and snow avalanches in mountainous areas. They always include effects on soil and vegetation, as these are often used as natural tools to attain the expected results. Natural soil and vegetation in the intervention site and surroundings can also be directly or indirectly affected by the operations. NBS therefore have collateral effects on these key components of terrestrial ecosystems and on the ecosystem services they provide. Enhancing ecosystem services is a condition for any operation to be considered a NBS and, therefore, impacts on soil and vegetation should be assessed within the framework of NBS **impact evaluation**.

Impact evaluation is essential for building knowledge around the effectiveness of interventions and to progress towards the systematization of good practices under specific environmental conditions. With this aim in mind, impact evaluation assesses the causal effects of changes in soil and plant communities related to NBS intervention.

Impact monitoring is a continuous process that begins before the start of the operations and continues after they are completed. Monitoring allows one to assess the evolution of selected soil and plant indicators over time from a pre-operational or immediately post-operational (baseline) value towards their expected value at a **reference site** (performance monitoring). A reference final value should be specified for each indicator, and also the expected progression of the indicator over time, so that corrective interventions can be designed to correct problems and undesired trajectories and to give support to adaptive management) (Raymond *et al.*, 2017).

Reference sites are physically and biologically equal to the area affected by the operations but are undisturbed and show the optimal environmental potential of the site. The reference site represents the desired state to be attained in the area affected by NBS.

In temperate climates, given the parsimonious response of the soil-plant system to disturbances or manipulation, soil and plant monitoring can last a long time after the implementation of NBS, and a considerable amount of time may be required before progress toward some objectives (e.g. increase in soil carbon stocks, colonization of the area by trees, etc.) can be observed. Monitoring plans would ideally include ecosystem indicators that respond within short to medium timescales, to provide near-term indications and reduce long-term monitoring costs. In this case, monitoring also needs to occur at the temporal scale on which the relevant metrics operate.

In an ideal situation, if the implemented measures are appropriated and no unexpected disturbances occur, the new soil-plant system will slowly evolve from the post-operational state towards the desired reference state, and this process can be assessed through the evolution of quantitative and measurable **indicators**.

3.3.1 Choosing appropriate soil and plant indicators

A monitoring plan should include a suitable **set of indicators** that should be carefully measured before NBS is deployed.

Useful and operative indicators should satisfy the following requirements (Doran, 2002; EEA, 2023):

(a) they must inform about key ecosystem processes

(b) they must integrate physical, chemical, and biological properties

(c) they must be sensitive to management and climatic variations

(d) they must be reliable, reproducible, and applicable to a wide range of sites, and

(e) they must be accessible and practicable for agricultural specialists, producers, conservationists, and policy makers. Access to them involves the availability of analytical methods, and the indicator must be interpretable by the end user.

Given the great quantity of services provided by the soil and that geological events alter many soil characteristics in the physical, chemical, and biological fields, sets of indicators are necessary instead of just a single indicator. Indicators must represent the state of different soil functions vis-à-vis the baseline value and the desired value, which corresponds to the value of the indicator in the reference state.

Together with the final value, the expected evolution trend toward recovery should be provided, together with a timeline.

3.3.1.1 Soil and plant indicators for NBS implemented in the Capet Forest and the Santa Elena roadcut

This report focuses on plant and soil functions that provide useful co-benefits in the field of climate change mitigation and habitat for biological activity: carbon storage, nutrient cycling, and habitat for biological activity.

3.3.1.2 Preselection process

Unfortunately, up to now all efforts to achieve a universally applicable set of indicators to evaluate the ability of NBS to improve the ecosystem services provided by the soil-plant system have been in vain.

This is due to the context-dependent condition of soil-plant relationships, which are greatly influenced by biogeography, local climate, geology, topography and land use, and also by less conspicuous features such as land use history and landscape structure. Moreover, a myriad of factors affects the ability of plants and soil organisms to colonize newly created or restored areas, i.e. to spread, establish themselves, and thrive.

Adding to this challenge, even if some indicators can be used universally (e.g. the percentage of plant cover), their optimal reference value and the rate of change on the way from the baseline value to the reference value is once again case-specific.

In the PHUSICOS project, the case studies of the Santa Elena roadcut and the Capet Forest are located on the same mountain range, and the affected ecosystems share some key features such as very adverse topography, a mountain climate, instability of the geological substrate, and non-exploitation of forests (apart from grazing in the uppermost parts of the Capet Forest).

Therefore, as a first step we drew up a prospective list of soil and plant properties that we studied for their sensitivity to the maturation of the new soil-plant systems created in the Santa Elena roadcut and the improved plant cover in the Capet Forest. The list is based on the expertise of the research team and includes the properties shown in Table 3-10.

These properties were measured in the area of influence of the two NBS using a stratified sampling design, which means that we divided the study areas into homogeneous vegetation units according to their state of maturity, and distributed sampling points randomly within each of these units. By doing so, we identified which properties discriminate between the maturity stages of the plant-soil system and are therefore useful as information about the correct maturation of the recreated (Santa Elena) or improved (Capet Forest) systems.

Plant morphological traits and life forms were more indicative of post-operation progress than species composition. Soil biological properties were clearly more sensitive to post-operation ecosystem maturation than soil physical and chemical properties, which suggests that the monitoring programme should include indicators based on soil biota together with functional plant indicators, and that some soil physical and chemical indicators should also be measured to aid in the interpretation of the overall progress of the system.

SECTOR	ECOSYSTEM SERVICE	INDICATOR	Unit
Soil	Belowground C sequestration	Total organic carbon stock (Total C_{org})	$g\ C\ .\ m^{-2}$
		Labile organic carbon (C_{org} in the fast pool)	$g\ C\ .\ m^{-2}$
		Recalcitrant organic carbon (C_{org} in the slow pool)	$g\ C\ .\ m^{-2}$
		Physically protected organic C	%
	Soil physical resilience	Soil erodibility (aggregate stability)	mm
		Soil bulk density	$g\ cm^{-3}$
	Biodiversity provision	Microbial diversity	
		Microbial species richness	number of species
		Microbial species diversity	unitless
		Microbial species eveness	unitless
		Microbial catabolic diversity	unitless
		Invertebrate functional diversity	
		Flagellates	$mg\ C\ g^{-1}$ dry soil
		Amoebae	$mg\ C\ g^{-1}$ dry soil
		Ciliates	$mg\ C\ g^{-1}$ dry soil
		Total protists	$mg\ C\ g^{-1}$ dry soil
		Bacterial feeder nematodes	$mg\ C\ g^{-1}$ dry soil
		Fungal feeder nematodes	$mg\ C\ g^{-1}$ dry soil
		Plant-feeder nematodes	$mg\ C\ g^{-1}$ dry soil
		Omnivore nematodes	$mg\ C\ g^{-1}$ dry soil
		Predatory nematodes	$mg\ C\ g^{-1}$ dry soil
		Total nematodes	$mg\ C\ g^{-1}$ dry soil
		Predatory Mites	$mg\ C\ g^{-1}$ dry soil
		Nematophagous Mites	$mg\ C\ g^{-1}$ dry soil
		Nematophagous prostigmatic mites	$mg\ C\ g^{-1}$ dry soil
		Collembola	$mg\ C\ g^{-1}$ dry soil
		Fungivorous cryptostigmatic mites	$mg\ C\ g^{-1}$ dry soil
		Fungivorous Prostigmata	$mg\ C\ g^{-1}$ dry soil
		Diplura	$mg\ C\ g^{-1}$ dry soil
		Symphyla	$mg\ C\ g^{-1}$ dry soil
		Protura	$mg\ C\ g^{-1}$ dry soil
		Total microarthropods	$mg\ C\ g^{-1}$ dry soil
	Biodiversity functions	Carbon mineralization by the soil food web	$g\ C\ m^{-2}\ y^{-1}$
		Theoretical soil food web stability	y^{-1}
Plants	Aboveground C sequestration	Total aboveground carbon stock	$t\ C\ ha^{-1}$
	Biodiversity provision & treats	Species richness	number of species
		Species diversity	unitless
		Eveness	unitless
		Invasive species	Number of species
	Soil protection	Soil vegetation cover	%

Table 3-10. *List of soil and plant properties studied in the PHUSICOS project for potential use as indicators of improved soil and plant services in the Santa Elena roadcut and Capet Forest case studies.*

3.3.2 Selected plant and soil indicators for the Capet Forest and Santa Elena sites

Based on the abovementioned preliminary screening, we combined sensitive plant and soil properties to produce a set of indicators that can be used to monitor both study sites. The final set of indicators is shown in Table 3-11.

	Climate change mitigation	Biodiversity provision
Plant Indicators		
I.1 Aboveground carbon stock	X	
I.2 Aboveground carbon sequestration	X	
I.3 Total plant cover	X	X
I.4 Woody plant cover	X	X
I.5 Land cover evolution		X
I.6 Mortality and growth of planted saplings		X
I.7 Invasive species		X
Soil physical and chemical indicators		
I.8 Soil organic carbon content	X	
I.9. Carbon sequestration in soil	X	
Soil biological indicators		
I.10 SBQ Index (soil microarthropods)		X
I.11 Taxonomic and functional diversity (soil microbes)		X

Table 3-11. *Soil and plant indicators selected for monitoring the effect of NBS implemented in the Capet Forest and Santa Elena study cases on soil and plant ecosystem services (climate change mitigation and biodiversity provision).*

3.3.3 Plant indicators

Aboveground C stock (I.1) and aboveground CO_2 sequestration (I.2) in plants

Almost 85% of terrestrial aboveground carbon (C) is stored in forests (Rodger, 1993), which play a key role in the global carbon cycle by eliminating a substantial amount of carbon dioxide (Cc) from the atmosphere. C stock in living woody vegetation (shrubs and trees) is the result of the balance between its increase through plant growth and its decrease through cutting or mortality (Vayreda *et al.*, 2012). When growth surpasses losses, the result is a net CO_2 sequestration; on the contrary, if losses exceed growth, the result is a release of CO_2 to the atmosphere (CO_2 emission).

Both the C stock and CO_2 sequestration of forests are indicators of ecosystem services related to climate regulation; the stock, because storing C is a way to keep CO_2 (a greenhouse gas) out of the atmosphere, and sequestration because forests help to remove CO_2 from the atmosphere and, as a consequence, reduce the impact of climate change.

- **Sampling method**

Both study sites (Santa Elena and the Capet Forest) should be sampled for aboveground C stocks and CO_2 sequestration in years 2, 4, and 6 after the end of the operations, and every five years thereafter. Samplings should be done in late spring or in summer when there is no snow and there are more hours of sunlight.

In the Capet Forest, 32 sampling plots should be randomly located across the area using a regular grid of 100x100 m, giving a in total 32 sampling plots (Figure 3-8).

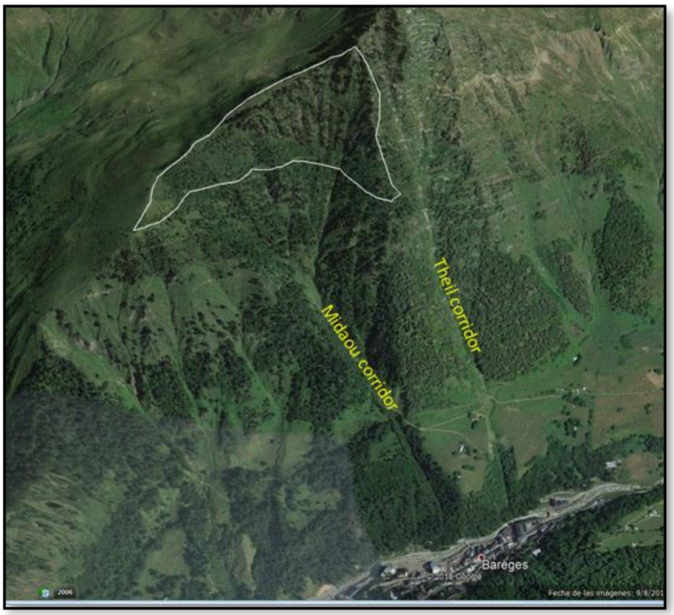

Figure 3-8. *Work area in the Capet Forest. The monitoring area is encircled in white.*

Plots should be circular with a radius of 10 m. The centre of the plots should be located with GPS (< 5 m accuracy) to be able to find them when they are resampled in the future.

In Santa Elena, with a small (about 0,05 ha) affected area, 5 of the 10 terraces created in the road cut should be sampled (Figure 3-9).

Figure 3-9. *Work area in the Santa Elena roadcut. The monitoring area includes ten 2-m-wide terraces of decreasing length (from 30 m for the lowest level to about 10m for the top level).*

In every sampling plot (in the Capet Forest) and terraces (at Santa Elena), all trees with a DBH (diameter of trunk at breast height) above 7.5 cm within the radius of the plot (distance to the center corrected for slope) should be measured. For each tree, the DBH (measured with a diameter tape), the height to the top (with a distance meter or equivalent) should be measured and the species noted. In a subplot of 5-meter radius the number of trees by species will be annotated distinguishing two size classes for regeneration: trees taller than 1 m and DBH < 2.5 cm and trees with a DBH of between 2.5 cm and 7.5 cm.

For each monitoring campaign, the total aboveground biomass per tree (kg/tree) and per plot is calculated using the equation that relates the tree DBH and height to aboveground biomass. This equation is species-specific, and it can be obtained from https://laboratoriforestal.creaf.cat/allometrapp/. All estimated biomass values are added to obtain the biomass per plot and multiplied by 31.83 to obtain the value equivalent to one hectare (ratio between one hectare=10,000 m^2 and the area of the sampling plot, r = 10 m, A = 314.16 m^2). Finally, the value is multiplied by 0.5 (1 kg OM = 0.5 kg C) to obtain the C stock (tC ha^{-1}).

The aboveground C sequestration or the C stock change per plot ($t \cdot ha^{-1} \cdot yr^{-1}$) is the difference between the C stocks of two successive forest inventories divided by 5 (years).

The average value of all plots is calculated and multiplied by the area of the study site to obtain the total C stock (tC) and the total C stock change (tC $\cdot$ yr^{-1}).

- **Desired evolution of the indicators over time**

In the absence of high intensity disturbances (unsustainable exploitation, snow avalanches, landslides, windstorms, wildfires, droughts, grazing...), carbon stock is expected to increase over time during the ecological succession until final stabilization. Scrub will replace grassland and trees will replace bushes throughout the succession process.

The rate of change is different for the two study sites:

- at the Capet Forest, about 30 years are necessary to achieve a pine forest. Based on the values measured in reference stands, carbon stocks are expected to be about 15 tC ha-1 in the 30-year-old pine forests.
- at Santa Elena, 5 years are necessary to achieve a dense bush cover and 60 years to obtain a spontaneous pine forest. Based on values from reference stands, carbon stocks are expected to be about 1.4 tC ha-1 in the 5-year-old *H. ramnoides* cover and about 42 tC ha-1 in the 100-year-old pine forests.

Total plant cover and woody plant cover (I.3 and I.4)

Plant cover and its woody fraction play a key role in controlling erosion by intercepting rainfall and improving water infiltration, enhancing soil protection, and carbon sequestration and are considered indicators of water regulation and prevention of snow avalanches and soil erosion. Moreover, the proportion of the recalcitrant soil carbon fraction is expected to increase as plant cover increases and includes growing proportions of woody species (Haynes, 2000; Pregitzer & Euskirchen, 2004).

- **Sampling method**

At both study sites, sampling should be done once a year in summer, at the phenological peak of the plants, repeated every year for the first 5 years and every 5 years thereafter.

Plots can be the very same as I.1 (Aboveground C stock in plants) and I.2 (Aboveground CO2 sequestration in plants) for the Capet Forest and the Santa Elena roadcut. Total plant cover (including herbs, shrubs and trees) and woody plant cover (shrubs and trees only) should be annotated at each plot. The percentage of total and woody plant cover will be determined by visual estimation (in the field or from aerial photographs, if available) of the percentage in vertical projection of the total and woody plant canopy covering the plot area.

- **Desired evolution of the indicators over time**

In the absence of high-intensity disturbances, total and woody plant cover is expected to increase exponentially until final stabilization.

In the Capet Forest, it will take about 5-10 years to reach > 50% of total plant cover and about 30 years to reach >50% of woody plant cover. In Santa Elena, it will take about 3-5 years to reach >50% of total plant cover and about 5-10 years to achieve >50% of woody plant cover.

Land cover evolution (I.5)

Vegetation or land cover maps series over time are a valuable indicator of vegetation dynamics. They show temporal changes due to primary or secondary succession, degradation or regression, regeneration or restoration of plant communities (Ichter *et al.*, 2014).

- **Monitoring method**

Vegetation and cover maps would be very useful for monitoring these restoration targets. A vegetation map (with EUNIS habitat types; https://eunis.eea.europa.eu) or a land cover map (with CORINE units; https://land.copernicus.eu/pan-european/corine-land-cover) of both study areas and adjacent zones should be created every 5 years by photointerpretation of aerial images and completed with the field data obtained from samplings.

The map should include the entire study area and the adjacent zones that can influence -or can be influenced- by the reforestation (in the Capet Forest) or stabilization and reforestation (in the Santa Elena roadcut). The map will be useful to calculate changes in vegetation or land cover over time, to detect the evolution of the plantations and any possible impacts (landslides, avalanches, etc.).

- **Desired evolution of the indicators over time**

In the absence of high-intensity disturbance, sallow thorn (*Hippophae rhamnoides*) scrub and then pine forest is expected to cover the restored roadcut at Santa Elena. Under similar low disturbance conditions, in the Capet Forest area plant communities should evolve over time from reforested prairies at high altitudes to shrubs and pine forests. In addition, if avalanches are minimized by tree plantations the avalanche corridors will 'scar heal' and will gradually be transformed from shrubs or young trees into mature forest.

The desired rate of change of the communities is the same as for indicators I.3 (*Total plant cover)* and I.4 *(Woody plant cover)*.

Mortality and growth of planted saplings (I.6)

- **Sampling method**

Both study sites (Santa Elena and Capet Forest) should be sampled for these two indicators in years 2, 4, and 6 after the end of the operations and every five years thereafter. Sampling should be done in late spring or in summer when there is no snow and there are more hours of sunlight.

In the Capet Forest, all saplings were inventoried just after planting. For monitoring, one out of every 4 tripod plantations (large or small collector) should be randomly chosen. In each collector (plantation units under tripods) the number of dead saplings per species will be registered and, for each living sapling, stem diameter (measured with a Vernier calliper 5 cm above the stem base) and height (with a measuring tape) will be measured.

At Santa Elena, all planted saplings should be inventoried at the end of the operations, immediately after planting. For every sapling, the inventory will include species name, diameter (measured with a Vernier calliper 5 cm above the stem base) and height (with a measuring tape). For monitoring, all saplings should be revisited to measure their diameter and height, noting dead specimens.

At both sites, and for each sampling campaign, the average value of the diameter at the base and average value of the height of all living seedlings (by species) should be calculated (in the Capet Forest, this calculation will be made separately for each collector). The average increase in diameter and height per collector and per species will be obtained by comparing two successive sampling campaigns divided by the time (in years) that has elapsed between them.

The mortality rate (in %) per species (and per collector in the Capet Forest) will be calculated as the ratio between the number of dead saplings and the number of live seedlings from the previous sampling campaign. In the Capet Forest, the average mortality rate per species will be obtained by averaging the values of all the collectors.

- **Desired evolution of the indicators over time**

Planted saplings are expected to foster the integration of the worked areas with plant communities covering the adjacent reference mountains.

The mortality of the planted saplings should be minimized. To date, no data have been available on sapling mortality or growth curves of the planted species in the region, which makes it impossible to establish desirable values over time for either of the two indicators. Therefore, data produced from this monitoring process would be very valuable to evaluate future restoration plans for plantations in the region.

Invasive species (I.7)

The richness of non-native (exotic) plant species is negatively related to altitudinal gradients worldwide, and invasive species (species that compete strongly with native species and can alter ecosystem properties) are rare in the montane and subalpine belts of European mountain ranges. However, anthropogenic impacts and disturbances (roads, urbanized areas, ski resorts, earthworks, etc.) positively influence the invasion of non-native plants along elevation gradients and in mountain ecosystems (Alexander *et al.*, 2016; Clements *et al.*, 2022). Restoration activities, such as reforestation and terrain stabilization, can create short-term disturbances that can be exploited by non-native species to colonize and spread in restored habitats and their surroundings.

Once established, even in small proportions, invasive species are very difficult to eradicate and can have significant negative impacts on natural ecosystems and socio-economic and human well-being.

- **Sampling method**

At both study sites, sampling should be carried out once a year in summer, at flowering peak, and repeated every year for the first five years (when the likelihood of the appearance of exotic species is greater).

In the Capet Forest, monitoring of invasive plants should require visual inspection of all collectors to determine the presence of invasive species.

At Santa Elena, all terraces should be visually inspected (by walking, binoculars or drone flight) to determine the presence of invasive species.

In both cases, the indicator for plant invasion will be expressed as the total number of invasive plant species in each monitoring campaign.

- **Desired evolution of the indicators over time**

In the short term, the likelihood of invasive species becoming established depends primarily on the proximity of propagules and the intensity of disturbance to the colonizable habitat. In any case, the likelihood of the presence of invasive species is low in the initial years, and zero in the medium and long term.

Alert flags and recommendations in the event of a warning

In the Capet Forest, annual monitoring of the saplings carried out in recent years (2017-2020) showed that mortality was low (<4%), and that it was falling year after year. Thus, it is likely that no reinforcement planting is necessary in the future. However, to guarantee higher tree diversity and plant cover, possible differences in mortality per species should be analysed. Unless a snow avalanche partially destroys a collector, reinforcement plantings would most likely not be necessary.

At Santa Elena, at the time of writing this monitoring plan there are no data on plant growth and mortality because the roadcut has not been reforested yet. If plant survival is very low, new reinforcement planting should be planned. The annual monitoring of survival rates, the percentage of total and woody cover, and growth of the remaining saplings per species will make it possible to extract conclusions about which species are the most suitable for restoration, in case reinforcement plantings have to be done in the future. In future monitoring, within 5-6 years and yearly during late spring or early summer, it is advisable to replace field sampling with a drone flight to assess changes in woody vegetation cover.

At both study sites, the appearance of more than two exotic species or the presence of one (or more) species with a rapid spread that could compete with the saplings will require the rapid removal of all specimens of alien or invasive species together with eradication programs.

3.3.4 Soil indicators

Soil monitoring should be scheduled to coincide with plant monitoring, in years 2, 4 and 6 after the end of the operations, and then every five years, both at Santa Elena and in the Capet Forest. Sampling campaigns should preferably be conducted in spring when soil and plant activity is high.

For all indicators, soil samples should be taken from the same plots designed for plant monitoring. In the Capet Forest, a $1m^2$ square subplot will be delimited in the centre of each of the 32 sampling plots selected for plant monitoring (see 3.3.1 (a)), and all soil samples will be taken within this area. In Santa Elena, the same 5 terraces selected for plant monitoring will be sampled for soil. At each of these terraces, three $1m^2$ square subplots will be delimited 10 m away from each other, beginning in the centre of each terrace (15 subplots in total). The material required for sample extraction will be specific for each indicator.

General soil characterization, particularly applicable at the Capet Forest and Santa Elena sites

A detailed analysis of soil physical, chemical, and biological properties was made in the Capet Forest as part of the description of the baseline of the site, before the implementation of NBS.

A similar description was made for the soils at the Santa Elena roadcut and the surrounding undisturbed forest areas (the data are available from the same source) before the start of operations. However, unlike in the Capet Forest, where natural soils were not perturbed by works, the natural soil was destroyed in the stabilization of the Santa Elena roadcut, and the newly created planting boxes were filled with materials and graded aggregates topped with a layer of topsoil of undetermined characteristics and origin. In the best-case scenario, this mixture might evolve towards a reasonable substrate allowing plant growing and, much later, towards a 'technosoil' whose characteristics might be compatible with those of the surrounding soils after many years.

In any case, this mixture of materials should be characterized as soon as possible after the end of the operations to help interpret the evolution of the planted vegetation and to monitor the potential formation of soil in the planting boxes that now cover the roadcut. For this characterization, the same 5 terraces selected for plant monitoring should be sampled for soil. Two sampling points should be marked on each of the five terraces, 10 m apart from each other in the centre of the terrace. At each sampling point, soil materials would be sampled at two depths (0-15 cm 20-35 cm) with a soil borer (Figure 3-10). The samples should be sent in properly labelled sealed plastic bags to soil expert labs to be analysed for texture, water holding capacity, total and organic carbon, total nitrogen, available phosphorous, main cations, pH, cation exchange capacity, and electric conductivity.

Soil organic carbon content (I.8) and carbon sequestration in soil (I.9)

Soil organic carbon loss is one of the main drivers of environmental degradation in Europe, and reversing this trend is among the priorities of the European Commission, in both agricultural environments and forests. Soil organic matter plays a central role in maintaining key soil functions and is an essential determinant of soil fertility and resistance against erosion (EC, 2002).

Soil carbon content (a quantity) and carbon sequestration in soil (a process) are different things. Soil carbon content can be directly measured from soil samples. Just as for aboveground carbon, carbon sequestration in soil is calculated by the difference in soil carbon content between two consecutive sampling dates.

Carbon sequestration is more difficult to monitor in soil than aboveground because changes in soil carbon content are slow and because carbon can migrate vertically though the soil profile and escape evaluation when working with the uppermost layers only.

- **Sampling and analysis method**

All samples should be taken undisturbed with soil corers of known dimensions, preferably 5 cm in diameter (or inside, depending on the corer shape) and always 15 cm deep (Figure 3-10).

***Figure 3-10**. Soil sampling with two different types of soil corers of squared (5 x 5 cm side) or circular (5 cm diameter) section 15 cm long. Both types of corers can be opened lengthwise to obtain undisturbed soil samples of constant known volume.*

- **Desired evolution of the indicators over time**

Soil carbon content is expected to increase as the restored soil matures in equilibrium with the introduced vegetation, meaning that CO_2 is being sequestered belowground.

- In the Capet Forest, 100 years after the implementation of NBS, soil organic carbon content is expected to be about 20%.
- In Santa Elena, 5 years after stabilization, soil organic carbon content should be about 5,5% under a bushy plant cover. 60 years later, under a pine forest, soil C content should be about 10%.

The rate of carbon sequestration in soils (as explained for plants) can be obtained by dividing the measured difference between two sampling dates by the number of years since the last sampling date.

Soil Biological Quality (SBQ) Index (for soil microarthropods) (I.10)

The abundance and biodiversity of belowground organisms is overwhelming. Considering only soil invertebrates, 1 m^2 of soil can shelter between 12,000 and 311,000 enchytraeids, 1 to 5 x 104 collembolans, and 1 to 10 x104 oribatid mites (Bardgett & Van Der Putten, 2014) among other less abundant groups. Soil fauna plays a key role in maintaining soil health and multifunctionality, as well as providing ecosystem services through processes such as organic matter shredding, translocation and decomposition, soil structure formation, water regulation and nutrient cycling (Menta *et al.*, 2020). Evaluating the whole soil diversity at the level of species is almost impossible in practice as we prefer to work at the level of functional groups or functional traits (Figure 3-11). Some of these groups are very well adapted to specific belowground conditions and are therefore highly sensitive to changes in soil quality (Delgado-Baquerizo *et al.*, 2020).

- **Sampling and analysis method**

Soil microarthropods should be extracted from undisturbed soil samples (see Figure 3-10 for adequate soil corers) 5 cm in diameter and 15 cm long by using batteries of Berlese funnels (Figure 3-12). Each soil sample is placed on a screen (mesh size equal to 2 mm) at the top of a funnel and an incandescent light bulb (40-60 Watts) is placed about 30 cm above the sample. As the sample dries out soil animals are stimulated to move downwards, which eventually causes the soil animals to fall through the sieve into a container with a preservative solution usually consisting of 75% alcohol mixed with water or glycerol. The extraction process can take about 7 days. Active funnels must be protected from draughts by protecting them in closed rooms.

A different index can be calculated from the observation, classification and counting of the extracted specimens at diverse resolution levels (ranging from total number of specimens to number of specimens of a particular species) under a stereomicroscope.

To monitor the effect of NBS applied on soil microarthropod biodiversity in Santa Elena and the Capet Forest, we propose the computation of the SBQ index.

Figure 3-11. *Some examples of the diverse morphotypes of soil mites (in the circle; D.E. Walter. https://beta.abmi.ca/biobrowser/species-group/mites-intro.html) and collembolans (in the rectangles; Andy Murray, https://www.chaosofdelight.org)*

Figure 3-12. *Berlese funnels used to extract microarthropods from undisturbed soil samples. Source http://soilbugs.massey.ac.nz/collection_berlese.php*

All extracted specimens are observed using a stereomicroscope and identified at order level except for Collembola, Diplura, Protura and Myriapoda -at class level-, and Acari -at sub-class-level. Then an EMI (Eco-morphologic index) value is assigned at each group. Qualitative Bone Index (QBI) is calculated by summation of all EMI values. All details about the calculation of the QBI can be found in Parisi *et al.*, (2005) and Menta *et al.* (2018).

The SBQ index assumes that the higher the soil quality, the higher the number of microarthropod groups well adapted to soil habitats will be. Adaptation can thus be assessed from the presence of diverse morphological characteristics, including reduction or loss of pigmentation and visual organs, reduced appendages (e.g. antennae or legs), thinner cuticle, absence of organs adapted to jumping, etc.

- **Desired evolution of the indicators over time**

As the restored system matures and soil quality grows, the SBQ value is expected to rise.

Soil microarthropods were extracted from samples taken soil reference systems in the Santa Elena zone and in the Capet Forest during the assessment of the soil quality baseline before the implementation of NBS. The results can provide reference values and rates of change for the two case studies.

Soil microbial taxonomic and functional diversity (I.11)

Soil microbial communities play a pivotal role in terrestrial ecosystems by reintegrating the essential nutrients into biogeochemical cycles, by regulating the quality of the atmosphere and the hydrosphere, reinforcing plant resilience and influencing the composition of plant communities by altering the competitive relationship between species (Nannipieri *et al.*, 2003). The diversity of functions performed by microorganisms in ecosystems has been recognized as the missing link between biodiversity patterns and ecosystem functions. There is increasing recognition that patterns of functional diversity may provide a more powerful test of theory than taxonomic richness.

Among a variety of analytical approaches to soil microbial diversity (Orgiazzi *et al.*, 2015), metagenomic analysis is a powerful tool for studying soil microbial functional capacities. Among the available metagenomics techniques, ‘Shotgun Metagenome Sequencing’ reveals 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 for monitoring soil biodiversity and ecosystem function across Europe.

- **Sampling and analysis method**

Metagenomic analyses are performed by expert companies that should be contacted sufficiently in advance of sampling campaigns to agree the shipment of soil samples in a safe manner. The company must be required to provide bioinformatic processing of the raw data.

Soil samples (about 40 gr each) are extracted from the 15 top cm of the soil with sterile individual sampling kits (ideally those used in medicine for stool analyses, Figure 3-13) to prevent cross contamination between samples, and kept refrigerated until prompt shipment to the laboratory. If shipment is not immediate, the samples must be stored at below -20ºC.

Figure 3-13*. Sampling kit (sterile spoon and container) for soil samples for microbial DNA analyses.*

Shotgun analyses are recommended to make monitoring data comparable to those produced during the baseline assessment in both case studies.

- **Desired evolution of the indicators over time**

Despite being of great diagnostic value, this indicator is not easy to interpret in the absence of experts. The functional composition of the soil microbiota is expected to converge with that described for the reference systems during the baseline assessment at both study sites (Figure 3-14).

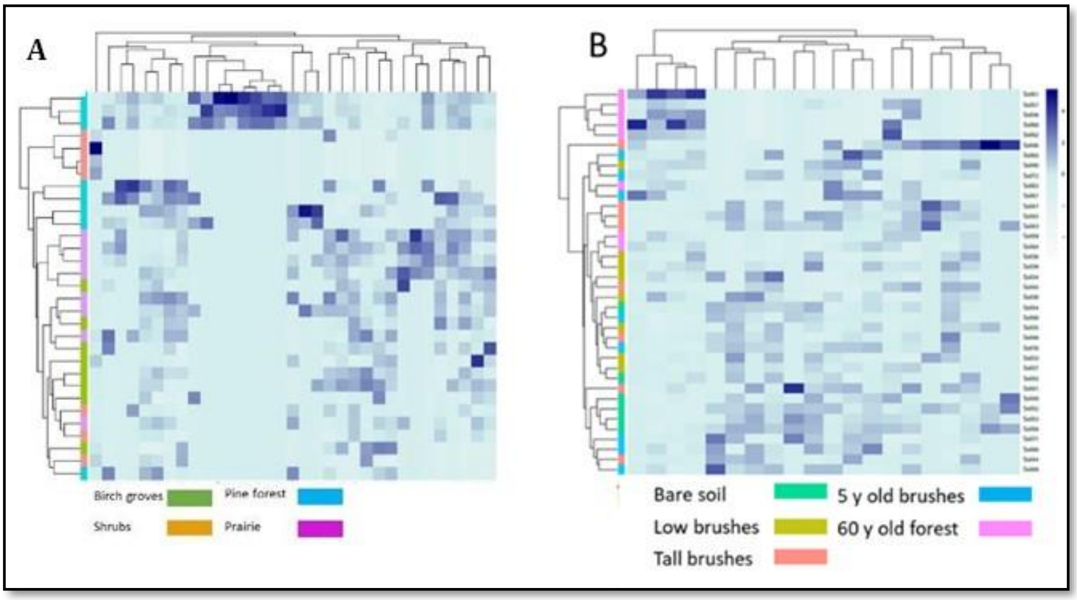

Figure 3-14. *Microbial community characterization of soil under different plant communities in the Capet Forest (A) and the Santa Elena (B) sites during the assessment of the preoperational baseline.*

3.3.5 Recommendations regarding the soil monitoring at the Capet Forest and Santa Elena sites

Monitoring is a crucial part of NBS projects within a framework of adaptative management as it alerts about potential deviations of the effected environment from the desired evolution. Monitoring also allows learning from trial and error, which is the only way to gradually improve practice.

Monitoring is also necessary to progress towards NBS standards and certifications, the lack of which is one of the main obstacles to the widespread adoption of NBS.

Monitoring programs require measuring specific indicators before implementing any NBS, and on a regular basis long after it has been implemented. This means that monitoring plan must be incorporated into the NBS project cycle from the outset (including the planning phase) and that it must be discussed with all the social stakeholders invited to the communication activities carried out in the Living Labs.

Monitoring has associated costs, especially when environmental indicators are included. Therefore, monitoring costs must be included in the project budget and the responsibility for long-term monitoring must be clarified and guaranteed.

4 Recommendations for the implementation of NBS

The next two tables detail recommendations for technicians (Table 4-1) and politicians (Table 4-2), following the methodology outlined in sub-chapter 3.1.3. These recommendations are intended to be considered when considering NBS to reduce the natural hazards present in mountain areas, and to ease the decision-making process.

4.1 Aimed at technicians working with risk management

Steps	Recommendations
Acquisition of basic data	▪ Whenever possible, use tools such as LIDAR to acquire exhaustive data and information, in addition to optical imagery. ▪ **Try to get comprehensive, up-to-date and accurate data.** ▪ **Implement efficient tools for collecting, storing and sharing information to optimize investments in data collection (data that can be used for all public policies - risk management, land development, environmental protection, urban planning, tourism...), and to achieve quality modelling.** ▪ **Think on implementing alert tools that allow for the rapid reporting of geo-localized information from the field.**
Hazard modelling	▪ Implement modelling that uses innovative tools such as Lidar and innovative modelling software. ▪ Take care in producing clear, explicit and understandable tables for elected officials and authorities, distinguishing:

Steps	Recommendations
	○ All the parameters theoretically necessary to conduct accurate and quality modelling. ○ Accessible parameters (explaining the impact on the quality of results of missing/smoothed/aggregated data). ▪ Clearly explain the limitations of the models and the impact on the responsibilities of elected officials and managing authorities.
Risk modelling	▪ Conduct quantitative risk analyses. ▪ Explain the notion of risk to elected officials with all its elements. Be vigilant regarding the concepts, and in particular on the notion of vulnerability (physical vulnerability of exposed elements and the integration of systemic vulnerability -in particular- for road networks). ▪ Discuss the concepts of residual risk, acceptable risk, individual risk and societal risk with elected officials. ▪ Make the interdependence of the level of protection/costs/freedom and constraints on the territory clear. ▪ **Remind that NBS basically only intervene on the hazard element (hazard reduction), but not on the vulnerability of the exposed elements, nor on exposure to them.**
Determination of the geographical zones where NBS will be implemented and first assessments	▪ Provide quantified risk level evidence to identify priority areas for risk reduction. ▪ Identify the sectors where NBS will contribute significant results (especially with regard to hazard intensities and the possibility of effectively reducing these hazards - frequency and/or intensity). ▪ Identify the types of solutions that are, in principle, adapted to the type of hazard to be dealt with. ▪ **Remind that NBS are not in opposition to grey solutions. They can, depending on the case, be used alone or as a complement to grey solutions. Both (NBS and grey solutions) need engineering to variable degrees.**
Design and sizing of NBS	▪ Mobilize high-level skills to design and dimension high-performance structures. ▪ Integrate the constraints of local resources and local skills into the design of structures. It is essential to place the materials that can be mobilized locally (on the one hand to reduce the carbon footprint and on the other hand to favour local economic development) as an input parameter for design and sizing, not as a parameter to be adapted to the design and sizing. In other words, it is preferable to mobilize possibly lower quality materials and adapt the design of NBS (and their associated maintenance), rather than imposing higher quality materials and transporting them over long distances.
Validation of NBS	▪ Perform a preliminary validation of NBS at 4 levels: ○ Theoretical validation (calculation) by a competent body (university, approved control office...). ○ Validation on a reduced model or a real model in the laboratory (cf. modelling conducted at the University of Madrid within the framework of the PHUSICOS project). ○ Full-scale validation on a test site.

Steps	Recommendations
	○ Validation on a full-scale site on a 'natural' experimental site. ▪ **Mobilize test sites such as the one set up at EIFORSA as part of the PHUSICOS project (test platform for protective structures against rock falls, for the dimensioning of support structures...).** ▪ **Mobilize full-scale experimentation sites such as the one set up in the commune of Laruns (Gourzy) within the framework of the PHUSICOS project for boulder falls (role of the forest and protective structures).**
Operational implementation of NBS in the field	▪ Carry out the works according to the specifications given in the detailed design. ▪ Mobilize local skills to the maximum. ▪ List all the constraints and difficulties, impossibilities or adaptations in order to receive feedback later. ▪ Implement all solutions in compliance with safety regulations. ▪ Structure operational implementation with the project's communication plan. ▪ Check the consistency of the implementation of solutions with the vegetative cycles.
Feedback on the implementation of NBS	▪ **Obtain comprehensive feedback on the implementation of NBS, as much on the technical and financial aspects as on the administrative and planning aspects, in a closing seminar with all the stakeholders.** ▪ **Identify deviations and changes from the initial objectives and measure (quantify) the impacts.** ▪ **Make all the acquired data available and structure the geographical data within the GIS of the communities.** ▪ Make sure all data is digitized to be shared and thus contribute to the capitalization of knowledge about the territories. ▪ Update all the indicators used in the initial diagnosis and carry out a quantitative assessment of each component (risks, environment, society and local economic development). ▪ Complete the databases on NBS to enrich and share the experience acquired (cf. the database developed in the framework of the PHUSICOS project).
Definition and implementation of a management and monitoring framework for NBS	▪ Define the set of core indicators that will be monitored, related to: ○ Risk reduction (hazard reduction, exposure reduction, vulnerability reduction. ○ Technical feasibility (cost-benefit analysis of the intervention, use of adapted techniques and materials). ○ Impact on the environment and ecosystems (water, soil, vegetation, landscape, biodiversity). ○ Impact on society (quality of life, community involvement and governance, landscapes and sites). ○ Impact on the local economy (revitalization of marginal areas, strengthening of the local economy).

Steps	Recommendations
	▪ Monitor these core indicators once the NBS are implemented together with competent institutions and actors, on a regular basis and/or after each extraordinary event. ▪ Ensure a proper maintenance of the NBS on a regular basis.
Definition of a communication framework	▪ Produce clear and innovative communication materials by mobilizing all media (documents, video, digital applications, role-playing games, field visits, experimentation workshops...). ▪ Organize seminars/debates/talks under the auspices of local authorities to present, explain and promote NBS.

Table 4-1*. List of recommendations aimed at technicians when defining and implementing NBS for natural hazard reduction. In bold, appear the recommendations common to the technicians and politicians.*

4.2 Aimed at politicians, in charge of risk management

Steps	**Recommendations**
Acquisition of basic data	▪ Mobilize significant funding (knowledge of the territories is a necessity to implement integrated, balanced and sustainable policies). ▪ Capitalize on knowledge and data on hazard characterization in the territory. ▪ **Try to get comprehensive, up-to-date and accurate data.** ▪ **Implement efficient tools for collecting, storing and sharing information to optimize investments in data collection (data that can be used for all public policies - risk management, land development, environmental protection, urban planning, tourism...) and achieve quality modelling.** ▪ **Think on implementing alert tools that allow for rapid reporting of geo-localized information from the field.** ▪ Promote the development of cloud-based Geographic Information Systems to optimize investments in data collection and have up-to-date information, and to have the skills to use these tools at local government level. ▪ Involve the population in the reporting of information (crowd-sourcing) thus improving the risk culture.
Risk modelling	▪ Understand the difference between hazards and risks. ▪ Understand the difference between the elements of risk to define the right actions to take: ○ Reduce the hazard: implement actions to reduce the frequency and/or intensity of the phenomena (notably with the help of NBS). ○ Reduce the vulnerability of exposed elements: reinforce elements, set up communication mesh networks. ○ Manage the exposure of the elements: through land use planning, the regulation of vehicle flows, the management of parking areas... etc. ▪ Understand the concepts of residual risk, acceptable risk, individual risk and societal risk.

Steps	Recommendations
	▪ **Remind that NBS basically only intervene on the hazard element (hazard reduction), not on the vulnerability of the exposed elements nor on the exposure.**
Determination of the geographical zones where NBS will be implemented and first assessments	▪ Define the priority sectors and select, with the help of technicians, the most appropriate risk reduction solutions with regard to: ○ The expected effectiveness of the solutions (ability to reduce risks). ○ Costs to be agreed upon according to available budgets and expected residual risks. ○ Maintenance of the systems implemented (level of maintenance required, who should provide this maintenance - are the technical services of the communities able to provide this maintenance?). ○ The responsibilities of mayors and managers (remember that there is no regulatory and normative framework for most NBS). ▪ **Remind that NBS are not in opposition to grey solutions. They can, depending on the case, be used alone or as a complement to grey solutions. Both (NBS and grey solutions) need engineering to variable degrees.**
Design and sizing of NBS	▪ Discuss with the designers of NBS the possible resources that can be mobilized at the local level: type of material, capacity of local companies to supply these materials (quantity, deadlines, price). ▪ Identify -upstream of the design and sizing phases- possible local skills to implement solutions and ensure maintenance. ▪ Discuss with the designers of the solutions throughout the design and sizing phase to 'pre-validate' the operational implementation of the solutions that will have been defined: materials, local skills, local administrative constraints, procurement and public procurement code.
Validation of NBS	▪ Encourage the setting up and the perpetuation of experimentation sites (e.g. Gourzy in the commune of Laruns). ▪ **Mobilize test sites such as the one set up in EIFORSA as part of the PHUSICOS project (test platform for protective structures against rock falls, for the dimensioning of support structures...).** ▪ **Mobilize full-scale experimentation sites such as the one set up in the commune of Laruns (Gourzy) within the framework of the PHUSICOS project for boulder falls (role of the forest and protective structures).**
Operational implementation of NBS in the field	▪ Mobilize all stakeholders (local authorities, State, natural parks, network managers, ...) to remove all administrative constraints and avoid delays in the implementation of *in situ* solutions. ▪ Set up working groups upstream to identify these constraints, find operational solutions and limit conflicts and blockages. ▪ Define 'reasonable' specifications and consultation files for companies. ▪ Encourage local companies to join consortia for the operational implementation of NBS and subsequent maintenance.
Feedback on the implementation of NBS	▪ **Obtain comprehensive feedback on the implementation of NBS, as much on the technical and financial aspects as on the administrative and planning aspects, in a closing seminar with all the stakeholders.**

Steps	Recommendations
	▪ **Identify deviations and changes from the initial objectives and measure (quantify) the impacts.** ▪ **Make all the acquired data available and structure the geographical data within the GIS of the municipality or region.**
Definition and implementation of a management and monitoring framework for NBS	▪ Establish a framework for managing and monitoring NBS, to determine: ○ The frequency and modalities of monitoring works. ○ The criteria and modalities of maintenance of the works (who does what and when) by integrating the budgetary and financial aspects. ○ Criteria and modalities for the removal of NBS structures (who does what and when), integrating budgetary and financial aspects if these structures prove to be unnecessary or deficient, or if they are likely to increase risks or degrade the environment. ○ The definition of the responsibilities and obligations of each of the stakeholders (communities, State, public organizations, technicians, companies). ○ Updates of diagnostic indicators (risks, environment, society, and local economic development), defining the frequencies and stakeholders to be mobilized as well as the actions to be taken in case of undesired or undesirable evolution of one or several indicators. Note: this management and monitoring framework can be an opportunity to co-build integrated strategies for risk management, territorial development, and environmental protection (such as integrated natural hazard/forestry management) among all stakeholders.
Definition of a communication framework	▪ Define all the communication actions, necessary means and targets to inform, raise awareness and involve all stakeholders, especially the local population. ▪ Set up a governance system to reinforce the acceptability of the proposed solutions and to identify possible blocking points. Note: this communication framework is to be put in place from the beginning of NBS implementation projects and is cross-cutting to all the steps presented above. This communication also aims to make all stakeholders understand the challenges of NBS, their interest, their limits, and their constraints. In particular it is a question of explaining the notions of risk with the balance to be found between protection, development, and costs.

Table 4-2. *List of recommendations aimed at politicians when defining and implementing NBS for natural hazard reduction. In bold, appear the recommendations common to the technicians and politicians.*

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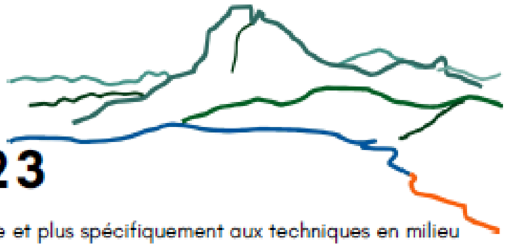
6 Appendices

Appendix A

Agenda of the two-day event: training day and results seminar.

Figure 6-1, Figure 6-2, Figure 6-3 and Figure 6-4 present the detailed agenda in French.
Figure 6-5, Figure 6-6, Figure 6-7 and Figure 6-8 present the detailed agenda in Spanish.

Figure 6-1. Page 1 of detailed agenda of two-day event organized in April, 11th and 12th in Laruns (in French).



JOURNÉE FORMATIVE
MARDI 11 AVRIL 2023

- **Objectif :** Introduire aux techniques de Génie Biologique et plus spécifiquement aux techniques en milieu montagnard.
- **Public cible :** techniciens des administrations publiques des forêts et routes; petites et moyennes entreprises des secteurs du bois et de la construction; cabinets conseils spécialisés sur les risques naturels, géotechnique, etc.

zoom https://us06web.zoom.us/j/83493876018?pwd=TGxkTytxM0RmcXExdi9tR1BFR3ZrQT09

8:45 - 9:00	Bienvenue et inscriptions
9:00 - 9:15	Introduction sur le contexte pyrénéen, concept des solutions fondées sur la nature **Observatoire Pyrénéen du Changement Climatique (OPCC) de la Communauté de Travail des Pyrénées (CTP) - Didier VERGÈS**
9:15 - 9:30	Introduction au contexte en Vallée d'Ossau, exploitation forestière dans les montagnes béarnaises et potentiel des Solutions fondées sur la nature (SfN) **Institution Patrimoniale du Haut Béarn (IPHB) - Jean-Michel MEHL**
9:30 - 10:00	Génie Biologique: une discipline fondée sur la Nature **Fédération Européenne pour le Génie Biologique (EFIB) - Paola SANGALLI**
10:00 - 11:00	Principales techniques de Génie Biologique pour la stabilisation des pentes **Fédération Européenne pour le Génie Biologique (EFIB) - Paola SANGALLI**
11:00 - 11:30	**Pause café**
11:30 - 12:30	Méthodologie pour le projet de stabilisation des pentes **Association Espagnole d'Ingénierie du Paysage (AEIP) - Guillermo TARDÍO**
12:30 - 14:00	**Pause déjeuner**
14:00 - 15:00	Du projet à la mise en oeuvre: exemples de projets de génie biologique pour la stabilisation de pentes **Association pour le Génie Végétal (AGéBio) - Klaus PEKLO** **Association Espagnole d'Ingénierie du Paysage (AEIP) - Albert SOROLLA**
15:00 - 15:30	Expériences et perspectives d'une entreprise locale pyrénéenne spécialisée dans le secteur du bois **Explotaciones e Impregnaciones Forestales SA (EIFORSA) - Eduardo FERNÁNDEZ**
15:30 - 17:30	Atelier de maquettes miniatures pour la stabilisation de pentes **AEIB, EFIB et AGéBio - Paola SANGALLI, Guillermo TARDÍO, Klaus PEKLO, Albert SOROLLA**
17:30 - 18:30	Mise en commun, apprentissages et conclusions finales **EFIB et OPCC - Paola SANGALLI et Eva GARCÍA BALAGUER**

Figure 6-2. *Page 2 of detailed agenda of two-day event organized in April, 11th and 12th in Laruns (in French).*

SÉMINAIRE DE RÉSULTATS
MERCREDI 12 AVRIL 2023

- **Objectif :** Présenter les résultats obtenus du projet PHUSICOS et débattre de la performance des solutions fondées sur la nature pour faire face aux risques naturels en zones de montagne.
- **Public cible :** autorités et techniciens des administrations publiques des forêts et routes; petites et moyennes entreprises des secteurs du bois et de la construction; cabinets conseils spécialisés sur les risques naturels, géotechnique, etc.

zoom https://us06web.zoom.us/j/85988352654?pwd=NHBPVXRTV3VMZG02QjBXbThkbUxnZz09

8:00 - 8:30 Bienvenue et inscriptions

8:30 - 9:00 Ouverture institutionnelle
- **Maire de la Commune de Laruns - Robert CASADEBAIG**
- **Commissaire de Massif des Pyrénées - Delphine MERCADIER-MOURE** (en ligne)
- **Président du GECT Pirineos - Pyrénées - José-Luis SORO** (tbc)
- **Directrice du Parc National des Pyrénées - Mélina ROTH**
- **Représentant technique de la Région Nouvelle Aquitaine - Matthieu BERGÉ** (tbc)

9:00 - 10:00 Concept des solutions fondées sur la nature et son importance croissante en Europe
- **Importance de la biodiversité dans les Solutions fondées sur la Nature (SfN)**
  Pilar ANDRÉS PASTOR - CREAF, partenaire PHUSICOS
- **Génie biologique en zones de montagne**
  Paola SANGALLI, Klaus PEKLO et Albert SOROLLA - AEIB, EFIB et AGéBio
- **Introduction à l'étude des leviers et obstacles entre SfN et solutions grises**
  Au nom de IIASA, partenaire PHUSICOS

10:00 - 11:30 Expériences et leçons apprises de la mise en place des solutions fondées sur la nature pour la gestion des risques naturels en zones de montagne: Capet, Artouste, Santa Elena et Erill la Vall
- **Importance des sciences et de la modélisation des risques**
  Clara LÉVY - BRGM, partenaire PHUSICOS
- **Visionnage de la vidéo du site d'Artouste**
- **Mention aux 'Living Labs' PHUSICOS dans les Pyrénées**
  Xavier CARBONNELL - ARC Mediación Ambiental
- **Table-ronde avec les experts techniques, modérée par Xavier CARBONELL**
  Santiago FÁBREGAS REIGOSA - GECT Pirineos - Pyrénées
  Alain BRUZY - Services RTM Pyrénées 64-65
  Carles RAÏMAT - Geo-Hazard Advisor, KUROBA4
- **Visionnage des vidéos des sites de Capet, Santa Elena et Erill la Vall**

11:30 - 12:00 **Pause café**

Figure 6-3. *Page 3 of detailed agenda of two-day event organized in April, 11th and 12th in Laruns (in French).*

SÉMINAIRE DE RÉSULTATS

MERCREDI 12 AVRIL 2023

- **Objectif :** Présenter les résultats obtenus du projet PHUSICOS et débattre de la performance des solutions fondées sur la nature pour faire face aux risques naturels en zones de montagne.
- **Public cible :** autorités et techniciens des administrations publiques des forêts et routes; petites et moyennes entreprises des secteurs du bois et de la construction; cabinets conseils spécialisés sur les risques naturels, géotechnique, etc.

12:00 - 13:30 Les autorités locales et la gestion intégrée du territoire

- **Cheminement réalisé par PHUSICOS dans les Pyrénées et apprentissages**
  Éric LEROI - Expert en Gestion de Risques, partenaire PHUSICOS
- **Table-ronde des élus du territoire, modérée par Éric LEROI**
  Robert CASADEBAIG, Maire de Laruns
  Pascal ARRIBET, Maire de Barèges
  Jean-Louis NOGUÈRE, Maire de Sers
  Sonià BRUGUERA, Maire de Vall de Boí
  Représentant de Comarca Alto Gallego (tbc)
  Représentant du Conseil Départemental 64 (tbc)

13:30 - 14:00 Conclusions du séminaire et perspectives futures

- **Représentant technique de la Région Nouvelle Aquitaine** - Matthieu BERGÉ (tbc)
- **Présidente de la Fédération Européenne pour le Génie Biologique (EFIB)** - Paola SANGALLI
- **Directeur de la Communauté de Travail des Pyrénées (CTP)** - Jean-Louis VALLS
- **Coordinatrice de l'OPCC - CTP** - Eva GARCÍA BALAGUER

14:00 - 15:00 **Pause déjeuner**

15:00 - 17:00 Visite (facultative) du site Artouste et des travaux de PHUSICOS (sur inscription)



Figure 6-4. *Page 4 of detailed agenda of two-day event organized in April, 11th and 12th in Laruns (in French).*

Figure 6-5*. Page 1 of detailed agenda of two-day event organized in April, 11th and 12th in Laruns (in Spanish).*

JORNADA FORMATIVA

MARTES 11 DE ABRIL 2023

- **Objetivo:** Introducir las técnicas de bio-ingeniería y más concretamente a las técnicas en un entorno montañoso.
- **Público meta:** técnicos de administraciones públicas forestales y de carreteras; pequeñas y medianas empresas de los sectores de la madera y la construcción; consultorías especializadas en riesgos naturales, geotécnica, etc.

zoom https://us06web.zoom.us/j/83493876018?pwd=TGxkTytxM0RmcXExdl9tR1BFR3ZrQT09

8:45 - 9:00	Bienvenida e inscripciones
9:00 - 9:15	Introducción sobre el contexto pirenaico, concepto de las soluciones basadas en la naturaleza **Observatorio Pirenaico del Cambio Climático (OPCC) de la Comunidad de Trabajo de los Pirineos (CTP) - Didier VERGÈS**
9:15 - 9:30	Introducción al contexto del Valle de Ossau, gestión y producción forestal en las montañas de Béarn y potencial de las soluciones basadas en la naturaleza (SbN) **Institution Patrimoniale du Haut Béarn (IPHB) - Jean-Michel MEHL**
9:30 - 10:00	Bio-ingeniería: una disciplina basada en la Naturaleza **Federación Europea de Bioingeniería del Paisaje (EFIB) - Paola SANGALLI**
10:00 - 11:00	Principales técnicas de bio-ingeniería para la estabilización de laderas **Federación Europea de Bioingeniería del Paisaje (EFIB) - Paola SANGALLI**
11:00 - 11:30	**Pausa café**
11:30 - 12:30	Metodología para el proyecto en la estabilización de laderas **Asociación Española de Ingeniería del Paisaje (AEIP) - Guillermo TARDÍO**
12:30 - 14:00	**Pausa comida**
14:00 - 15:00	Del proyecto a la ejecución: ejemplos de proyectos de bio-ingeniería para la estabilización de laderas **Association pour le Génie Végétal (AGéBio) - Klaus PEKLO** **Asociación Española de Ingeniería del Paisaje (AEIP) - Albert SOROLLA**
15:00 - 15:30	Experiencias y perspectivas de una empresa local pirenaica especializada en el sector de la madera **Explotaciones e Impregnaciones Forestales SA (EIFORSA) - Eduardo FERNÁNDEZ**
15:30 - 17:30	Taller de maquetas miniaturas para la estabilización de laderas **AEIB, EFIB y AGéBio - Paola SANGALLI, Guillermo TARDÍO, Klaus PEKLO, Albert SOROLLA**
17:30 - 18:30	Puesta en común, aprendizajes y conclusiones finales **EFIB et OPCC - Paola SANGALLI y Eva GARCÍA BALAGUER**

Figure 6-6. *Page 2 of detailed agenda of two-day event organized in April, 11th and 12th in Laruns (in Spanish).*

SEMINARIO DE RESULTADOS
MIÉRCOLES 12 DE ABRIL 2023

- **Objetivo:** Presentar los resultados obtenidos en el proyecto PHUSICOS y debatir la eficacia de las soluciones basadas en la naturaleza para hacer frente a los riesgos naturales en las zonas de montaña.
- **Público meta:** autoridades y técnicos de administraciones públicas forestales y de carreteras; pequeñas y medianas empresas de los sectores de la madera y la construcción; consultorías especializadas en riesgos naturales, geotécnica, etc.

zoom https://us06web.zoom.us/j/85988352654?pwd=NHBFVXRTV3VMZG02QjBXbThkbUxnZz09

8:00 - 8:30 Bienvenida e inscripciones

8:30 - 9:00 Apertura institucional
- **Maire de la Commune de Laruns - Robert CASADEBAIG**
- **Commissaire de Massif des Pyrénées - Delphine MERCADIER-MOURE** (en línea)
- **Presidente del GECT Pirineos - Pyrénées - José-Luis SORO** (tbc)
- **Directrice du Parc National des Pyrénées - Mélina ROTH**
- **Représentant technique de la Région Nouvelle Aquitaine - Matthieu BERGÉ** (tbc)

9:00 - 10:00 Concepto de soluciones basadas en la naturaleza y su relevancia creciente en et Europa
- **Importancia de la biodiversidad en las soluciones basadas en la naturaleza (SbN)**
  Pilar ANDRÉS PASTOR - CREAF, socio PHUSICOS
- **Bio-ingeniería en zonas de montaña**
  Paola SANGALLI, Klaus PEKLO y Albert SOROLLA - AEIB, EFIB y AGéBio
- **Introducción al estudio de palancas y obstáculos de SbN y soluciones grises**
  En nombre de IIASA, socio PHUSICOS

10:00 - 11:30 Experiencias y lecciones aprendidas del desarrollo de soluciones basadas en la naturaleza para la gestión de riesgos naturales en zonas montañosas: Capet, Artouste, Santa Elena y Erill la Vall
- **Relevancia de las ciencias y de la modelización de los riesgos**
  Clara LÉVY - BRGM, socio PHUSICOS
- **Visualización del video del sitio de Artouste**
- **Mención a los 'Living Labs' PHUSICOS en los Pirineos**
  Xavier CARBONNELL - ARC Mediación Ambiental
- **Mesa-redonda de expertos técnicos, dinamizada por Xavier CARBONELL**
  Santiago FÁBREGAS REIGOSA - GECT Pirineos - Pyrénées
  Alain BRUZY - Services RTM Pyrénées 64-65
  Carles RAÏMAT - Geo-Hazard Advisor, KUROBA4
- **Visualización de los videos de los sitios de Capet, Santa Elena et Erill la Vall**

11:30 - 12:00 **Pausa café**

Figure 6-7. *Page 3 of detailed agenda of two-day event organized in April, 11th and 12th in Laruns (in Spanish).*

SEMINARIO DE RESULTADOS
MIÉRCOLES 12 DE ABRIL 2023

- **Objetivo:** Presentar los resultados obtenidos en el proyecto PHUSICOS y debatir la eficacia de las soluciones basadas en la naturaleza para hacer frente a los riesgos naturales en las zonas de montaña.
- **Público meta:** autoridades y técnicos de administraciones públicas forestales y de carreteras; pequeñas y medianas empresas de los sectores de la madera y la construcción; consultorías especializadas en riesgos naturales, geotécnica, etc.

12:00 - 13:30 Las autoridades locales y la gestión integrada del territorio

- **Recorrido de PHUSICOS en los Pirineos y aprendizajes**
  Éric LEROI – Experto en Gestión de Riesgos, socio PHUSICOS
- **Mesa-redonda con representantes electos del territorio, dinamizada por Éric LEROI**
  Robert CASADEBAIG, Alcalde de Laruns
  Pascal ARRIBET, Alcalde de Barèges
  Jean-Louis NOGUÈRE, Alcalde de Sers
  Sonià BRUGUERA, Alcalde de Vall de Boí
  Representante de Comarca Alto Gallego (tbc)
  Representante de Conseil Départemental 64 (tbc)

13:30 - 14:00 Conclusiones del seminario y perspectivas futuras

- **Representante técnico de la Région Nouvelle Aquitaine** – Matthieu BERGÉ (tbc)
- **Presidente de Federación Europea de Bioingeniería del Paisaje (EFIB)** – Paola SANGALLI
- **Director de la Comunidad de Trabajo de los Pirineos (CTP)** – Jean-Louis VALLS
- **Coordinadora del OPCC - CTP** – Eva GARCÍA BALAGUER

14:00 - 15:00 **Pausa comida**

15:00 - 17:00 Visita (opcional) del sitio de Artouste y de las soluciones de PHUSICOS (previa inscripción)

Figure 6-8. *Page 4 of detailed agenda of two-day event organized in April, 11th and 12th in Laruns (in Spanish).*

Appendix B

List of participants.

Figure 6-9 and Figure 6-10 details the participants during the event.

	Nombre / Prénom	Apellidos / Nom	Empresa / Entreprise / Institución / Institution
1	Marc	Ancely	Arbisanat
2	Beatriz	Barinaga Mugica	Asmatu S.L.
3	Alejandro	Cantero	HAZI
4	Carles	Fañanás	Departament d'Acció Climàtica, Alimentació i Agenda Rural de la Generalitat de Catalunya
5	Carolina	García Suikkanen	Confederación Hidrográfica del Ebro
6	Lorenzo	Serrano Zuñeda	DG de Medio Natural y Gestión Forestal del Gobierno de Aragón
7	Olivier	Valfort	DDTM 64
8	Jean-Michel	Melh	Institut Patrimonial du Haut-Béarn (IPHB)
9	Clara	Lévy	BRGM
10	Joël	Coubluc	Mairie de Laruns - Adjoint au Maire
11	Jean-Marc	Moreno	Mairie de Laruns - Adjoint au Maire
12	Gérard	Lamagnère	Mairie de Laruns - Conseiller Municipal
13	Toni	Jobbe-Duval	Explotaciones e Impregnaciones Forestales SA (EIFORSA)
14	Robert	Casadebaig	Mairie de Laruns - Maire
15	Nélida	García Sanz	DG de Cambio Climático y Educación Ambiental del Gobierno de Aragón
16	Anne	Busselot	Commissariat de Massif des Pyrénées
17	Josep Ma	Caba	SOLUTIOMA
18	Eva	García Balaguer	Communauté de Travail des Pyrénées (CTP) - Observatoire Pyrénéen du Changement Climatique (OPCC)
19	Didier	Vergès	Communauté de Travail des Pyrénées (CTP) - Observatoire Pyrénéen du Changement Climatique (OPCC)
20	Eric	Leroi	R&D
21	Pilar	Andrés	CREAF
22	Paola	Sangalli	SCIA SL / EFIB
23	Sergio	Sangalli	SCIA SL
24	Klaus	Peklo	Klaus Peklo
25	Albert	Sorolla	Naturalea
26	Frédéric	Berger	INRAE

Figure 6-9. *Detail of participants during the first day of the event (training day, 11/04/2023).*

	Nombre / Prénom	Apellidos / Nom	Empresa / Entreprise / Institución / Institution
1	Marta	Pérez Banco	AECT Pirineos - Pyrénées
2	Santiago	Fábregas Reigosa	AECT Pirineos - Pyrénées
3	Alain	Bruzy	RTM ONF
4	Brice	Dupin	ECO-ALTITUDE
5	Clara	Lévy	BRGM
6	Marc	Ancely	Arbisanat
7	Nélida	García Sanz	DG de Cambio Climático y Educación Ambiental del Gobierno de Aragón
8	Olivier	Valfort	DDTM 64
9	Lorenzo	Serrano Zuñeda	DG de Medio Natural y Gestión Forestal del Gobierno de Aragón
10	Sylvie	Cassau	Mairie de Laruns - Adjointe au Maire
11	Eric	Leroi	R&D
12	Célia	Amorich	ONF
13	Sònia	Bruguera	Vall de Boí
14	Carles	Raïmat	Kuroba4
15	Jona	Trujillo	Kuroba4
16	Christian	Paille-Barrere	Conseil Départemental 64
17	Jean-Louis	Noguère	Mairie de Sers - Maire
18	Albert	Sorolla	Naturalea
19	Pascal	Arribet	Mairie de Barèges - Maire
20	Ricard	Baró	Fent Cami
21	Carles	Fañanás	Departament d'Acció Climàtica, Alimentació i Agenda Rural de la Generalitat de Catalunya
22	Alejandro	Cantero	HAZI
23	Klaus	Peklo	Klaus Peklo
24	Carolina	García Suikkanen	Confederación Hidrográfica del Ebro
25	Étienne	Czernecka	Sud Ouest - Journaliste
26	Eva	García Balaguer	Communauté de Travail des Pyrénées (CTP) - Observatoire Pyrénéen du Changement Climatique (OPCC)
27	Didier	Vergès	Communauté de Travail des Pyrénées (CTP) - Observatoire Pyrénéen du Changement Climatique (OPCC)
28	Xavier	Carbonell	ARC Mediación Ambiental
29	Mélina	Roth	Parc National des Pyrénées
30	Delphine	Mercadier	Commissariat de Massif des Pyrénées
31	Jean-Louis	Valls	Communauté de Travail des Pyrénées (CTP)
32	Frédéric	Berger	INRAE

Figure 6-10. *Detail of participants during the second day of the event (results seminar day, 12/04/2023).*

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