OPERANDUM

OPEn-air laboRAtories for Nature baseD solUtions to Manage hydro-meteo risks

FIELD GUIDE FOR THE IDENTIFICATION AND OPERATIONALISATION OF NBS AT OAL – UK

naturalea

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University for the Common Good

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Short Description
This document reports on the rationale for identifying Nature-based Solutions (NBS) against shallow landslides and surface erosion at OAL-UK, and it outlines the strategies followed for the co-creation, co-design, and co-development of the identified NBS at OAL-UK. This document intends to be a field guide prior to the co-deployment and operationalisation of NBS at OAL-UK, and it specifically aligns with the work undertaken within the work packages (WP) 2, 3, 4, and 8 of OPERANDUM. The document includes a description of the OAL, a conceptual approach for NBSs selection at the OAL level, a description of the identified NBSs, a botanical description of the selected NBSs, a conceptual approach for monitoring the performance of and manage the identified NBSs, and alignment of the implementation of the NBS within the wider OPERANDUM co-design and stakeholder engagement strategies.

Dissemination level		
PU	Public	X
CO	Confidential, only for Members of the Consortium, including the EU Commission Services	

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1 Introduction

This document reports on the rationale for identifying Nature-based Solutions (NBS) against shallow landslides and surface erosion at OAL-UK, and it outlines the strategies followed for the co-creation, co-design, and co-development of the identified NBS at OAL-UK. This document intends to be a field guide prior to the co-deployment and operationalisation of NBS at OAL-UK, and it specifically aligns with the work undertaken within the work packages (WP) 2, 3, 4, and 8 of OPERANDUM. The documents includes a description of the OAL, a conceptual approach for NBSs selection at the OAL level, a description of the identified NBSs, a botanical description of the selected NBSs, a conceptual approach for monitoring the performance of and manage the identified NBSs, and alignment of the implementation of the NBS within the wider OPERANDUM co-design and stakeholder engagement strategies.

2. OAL Characteristics

2.1. Location and Socio-economic features

OAL-UK is located in Northeast Scotland and adjacent to Catterline Bay (Fig. 1). OAL-UK represents a small-scale (i.e. 0.4 km^2), culturally significant OAL due to its scenic beauty, portrayed by renowned Scottish painters in the past. The site lies close to the Fowlsheugh coastal nature reserve, known for its high cliff formations and habitat supporting prolific seabird nesting colonies.

Figure 1. Location of OAL-UK and aerial image of the OAL. Image source: TomTom (2019).

OAL-UK is located approximately 7 miles south of Stonehaven, Aberdeenshire (WGS84 Long: -2.21 Lat: 56.90 Fig. 1). Catterline Bay hosts a small residential community (ca. 150 inhabitants) which includes a primary school. The community is settled atop the cliffs and slopes adjacent to the bay. Catterline's residents use the slopes, cliffs, beach and shores for minor fishing activities and for recreational purposes. There is a divers club (https://www.montrosesubaquaclub.co.uk/about-us/) that is operational during the summer months, and maintains an access road to the beach. Additionally there is a coastal rowing club (http://catterline.org/coastalRowing) that launches from Catterline Bay from March – October. Paddleboarding activities also take place at Catterline Bay during the summer. Catterline's residents are actively involved in the implementation of Nature-based Solutions (NbSs) against landslides and coastal erosion hazards through the Catterline Braes Action Group –i.e. CBAG https://www.cbag.org.uk/.

2.2. Climate

OAL-UK is located within the temperate humid climate zone (Cgc: subpolar oceanic climate; Köppen, 1884). The mean annual temperature at the site is 8.9ºC and the mean annual rainfall is 565.13 mm (2011-2014; Gonzalez-Ollauri and Mickovski, 2016). The precipitation at the site is characterised by frequent, low- intensity rainfall events (Gonzalez-Ollauri and Mickovski, 2016).

2.3. Geology and Edaphology

The basement geology of the area is Devonian age conglomerate, similar to that seen beneath Dunnotar Castle, although are dipping much more gently in Catterline. A detailed description of the Catterline Conglomerate Formation from the BGS website *(http://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=CATC*) is: "A bimodal, clast-supported conglomerate with clasts mainly of lava, but also containing psammite, quartzite, vein-quartz and feldspar porphyry in a mediumgrained lithic sandstone matrix, with single flows of andesite and three sandstone members."Quaternary glacial deposits of unknown composition and thickness are expected to uncomfortably rest upon the basement rocks.

With regard to soil features, well-drained (saturated hydraulic conductivity (Ks): 5.82×10^{-05} m s^{-1}), shallow (ca. 600 mm), sloped (25-50º), and landslide-prone silty sands (sand: 79.82%; silt: 5.85 %; clay: 3.08%) overlie the conglomerate rock. The topsoil at the site (0-400 mm below ground level, b.g.l.) has a mean dry bulk density of 0.86 g cm^{-3}, a drained cohesion of 33.4 kPa, a mean angle of internal friction of 22º and a mean organic matter content of 5.57 %.

2.4. Topography

The site topography is dominated by sloped (25–50º) terrain and cliffs dropping into the North Sea (Fig. 2). These are combined with a flatter inland area that is crossed by a stream leading to the formation of inclined riverbanks.

2.5. Land Cover

The vegetation of the study site is characteristic of temperate humid climates, comprising herbaceous weeds and grasses associated to disturbed grounds (Gonzalez-Ollauri and Mickovski, 2017c) intermixed with areas dominated by riparian trees and shrubs (e.g. willow, sycamore, ash, hawthorn), where oak and beech individuals can be also found. Agricultural crops of wheat, barley and potatoes surround the study site. There is also a 2 km-long stream within the OAL. Other land covers comprise urban and artificial land with a minor area covered by transport infrastructure, which represent 11 % of the OAL's total area.

Figure 2. Left: Bay, slopes and cliffs affected by shallow landslides and surface erosion at OAL-UK; Right: Access road to the beach at OAL-UK.

Location: name: Catterline (UK) coordinates: 56.9°N 2.2°W scale[1] (NBS): micro scale[1] (impact): watershed	**Hydro-meteorological risks** ✔ flood ✔ landslide ✔ storm surge ☐ drought	**Existing NBS** ☐ green ☐ blue/grey/hybrid ✔ unsystematic	**Intended NBS** ✔ green ✔ blue/grey/hybrid
Innovation ✔ definition ✔ co-design ☐ deployment ☐ monitoring/modeling ✔ KPI ☐ market development ☐ co-benefit			**Stakeholders** ✔ statutory authorities ✔ local government ✔ resident ✔ land owner/managers ☐ business ☐ research institutions ☐ civil protection ☐ cultural associations
Economic assets ✔ tourism/recreation ☐ biodiversity ☐ manufacturing industries ✔ agriculture/fishery ☐ cultural heritage	**Links to EU initiatives** ✔ Natura 2000 ☐ WFD ☐ EU-LIFE ☐ other EU Projects	**Major strategies to maximize impact** ✔ replication ✔ dissemination ☐ exploitation ✔ capacity building ☐ shifting policies	

Figure 3. Main features of OAL-UK defined in the frame of OPERANDUM.

3. Hydrometeorological hazards at OAL-UK

Three main hydrometeorological hazards act on OAL-UK. These are shallow and deep landslides, surface erosion, and coastal erosion. The soil materials comprising the slopes and cliffs at OAL-UK present silty sand texture. As a result, the mechanical strength of the slope forming materials is subject to changes under wetting and drying cycles, which make the OAL-UK prone to rainfall-induced landslides and surface erosion. These natural hazards are worsened in some sections of the OAL as a result of an overpopulation of rabbits and the outflow of a natural spring from which the local community used to retrieve water for consumption. Once the spring was closed, the water begun to outflow diffusively, saturating the slope-forming materials and thus reducing their mechanical strength. Currently, there are a number of active, and interlinked, shallow landslides and surface erosion processes at the OAL. Yet, historic records from pictures, photography, local testimonies, and news suggest that the former natural hazards have occurred at the OAL over time. Moreover, past spring tides in combination with storm surges have led to severe erosion episodes of the toe of the OAL's slopes and cliffs. This, in turn, weaken the slope forming materials further, becoming even more prone to rainfall-induced landslides and erosion. To our knowledge, there only is one major landslides episode reliably reported by the OAL's residents, and recorded at the meteorological station deployed *in situ* at the OAL (https://www.pedrox.com/weather/index.html). This occurred in October 2012 after two periods with prolonged rainfall occurring in the summer and October, respectively. From local testimonies, it seems that this episode was concurrent with spring tides and a storm surge episode, which worsened the landslides event. Through the examination of rainfall time series retrieved at the OAL for this period, we observed total rainfall amounts comprised between 30 and 40 mm, with durations comprised between 11 and 16 hours, and intensities ranging between 1.9 and 3.9 mm h^{-1}. With this, we established that an extreme hydrometeorological event likely to trigger severe landslides at OAL-UK could be selected on the basis of daily rainfall depths beyond 30 mm d^{-1}, which corresponds to ca. 5 % of annual rainfall concentrated in one event. Meteorological time series for the OAL-UK are available from late 2011 to present, so the examination of longer time series is not possible. The examination of these time series indicate that between 2011 and late 2018, five extreme episodes of have occurred at the OAL-UK (Table 1). The study of meteorological time series from nearby weather stations (e.g. Stonehaven) could be helpful but not meaningful, as Catterline presents a marked micro-climate (e.g. Gonzalez-Ollauri and Mickovski, 2016). In fact, through the study of meteorological records for Stoneheaven, where other landslide episodes have been recorded by local media (e.g. https://www.bgs.ac.uk/products/geohazards/landslide.html), suggest that extreme events with rainfall depths of 150 mm d^{-1} would be more representative. As for extreme events related to the storm surge episode allegedly occurring in October 2012, monthly extremes from Aberdeen's offshore sea monitoring station were examined (https://www.bodc.ac.uk/data/bodc_database/nodb/). From this dataset we retrieved the maximum records for wave height, tidal level, and surge recorded. These resulted in the following extremes: (i) Wave height > 4.0 m; (ii) tidal level > 4.815 m ; and (iii) surge > 0.59 m. We believe the combination of both prolonged period with rainfall and high sea levels represent the worse-case scenario at the OAL. In addition to the above-mentioned hydrometeorological hazards, riverbank erosion and flooding hazards are also contemplated at the

OAL-UK. There is a small-size stream at the OAL-UK which flow and water level does not experience substantial seasonal changes. The size and length of the stream and its flow conditions do not impose major hazards or risks to the OAL's community. However, we have observed some minor episodes of riverbank erosion and flooding at specific points of the riparian zone. We do not have records yet on river flow and height, but considering the small size of the catchment (i.e. ca. 0.4 km^2), we could assume that the same extreme events described above could potentially trigger changes in the river hydrodynamics with potential to lead to minor episodes of riverbank erosion and flooding.

Table 1. Extreme rainfall events recorded at OAL-UK from 2012 to 2017.

Rainfall extremes	Start	End	Rainfall intensity (mm h^{-1})	Total rainfall per event (mm)	Duration (h)
2012-07-18	2012-07-18 3:00	2012-10-12 18:00	1.93	30.8	16
2012-10-12	2012-10-12 5:00	2012-10-12 15:00	3.76	41.4	11
2015-07-04	2015-07-04 04:00	2015-07-04 14:00	2.78	30.6	11
2016-06-25	2016-06-24 23:00	2016-06-25 12:00	2.52	35.4	14
2017-06-06	2017-06-05 23:00	2017-06-07 06:00	1.27	40.8	32

4. Project rationale and approach to co-creation, co-design, co-development, and co-deployment of NBS at OAL-UK

Humans have transformed the Earth's landscapes over time. This transformation has overall improved welfare in human communities but also has created conflicts with the environment. Some of these conflicts are worsened by pursuing the creation of static elements in a dynamic world. In addition, landscape transformations may derive into situations in which humans cannot benefit from Nature anymore. Currently, humans are subject to the consequences derived from climate change. This creates extreme environmental conditions related to the occurrence of natural hazards, which provoke serious damages to human life and property. To mitigate natural hazards, humans have gained insight into hydrology, edaphology, meteorology, etc. Yet, we need comprehensive and multi-disciplinary approaches to be able to mitigate natural hazards derived from climate change. These approaches should take into account the dynamics and functioning of ecosystems. Integrated, ecology-based approaches to tackle natural hazards should work along with Nature. Nature-Based Solutions (NBS) are born with this idea in mind, as NBS can be defined as "lessons learnt from Nature" (Sahani et al., 2019). NBS should enable human communities to mitigate natural hazards while retrieving additional benefits or services -i.e. ecosystem services. Examples of NBS can be found in the techniques related to soil and water bioengineering. With NBS employing soil & water bioengineering techniques, the following environmental problems can be addressed:

- Landscape degradation
- Water recharge and pollution
- Drought
- Nutrient retention and cycling
- Runoff management and erosion control
- Slope stabilisation
- Diffuse pollution reduction
- Reduction of flood risks
- Regulation of temperature and humidity (i.e. climate regulation)

A key objective of OPERANDUM is to reduce hydro-meteorological risks in European territories through co-designed, co-developed, co-deployed, tested and demonstrated innovative NBS. The OPERANDUM project will strive to achieve this objective by involving local communities, authorities and other stakeholders within the decision and implementation processes (i.e. a co-creation process consisting of co-design, co-development and co-deployment). Hazards such as shallow landslides and erosion can be effectively addressed with soil bioengineering techniques that combine the use of plants, especially shrubs, with conventional civil engineering approaches.

One key feature to implement NBS effectively and sustainably is the use of local, natural materials. Natural materials, such as logs and plant cuttings, are less rigid than steel and concrete, and so they can evolve adapting to changing environmental conditions. NBS also need management and maintenance, but these are less costly and easier to implement than in conventional engineering projects.

Effective NBS that employ soil bioengineering techniques should use local and native plant materials. Sometimes other plant species can be introduced when there are not foreseen invasive issues. Newly introduced species should present features that enable the overlap of the ecological functions with respect to the local species. This will maintain the persistence of the ecological and structural functions and features of the host ecosystem in spite of climatic or environmental changes while increasing biodiversity. In fact, more diverse plant assemblages tend to be more resilient towards natural hazards and environmental change.

We propose in Figure 4 a conceptual approach illustrating the steps to follow from the identification of hydro-meteo hazards to the deployment and monitoring of specific NBS at a given OAL. In Sections 4.1 to 4.4. the processes of co-creation, co-design, co-development, and co-deployment at OAL-UK are outlined.

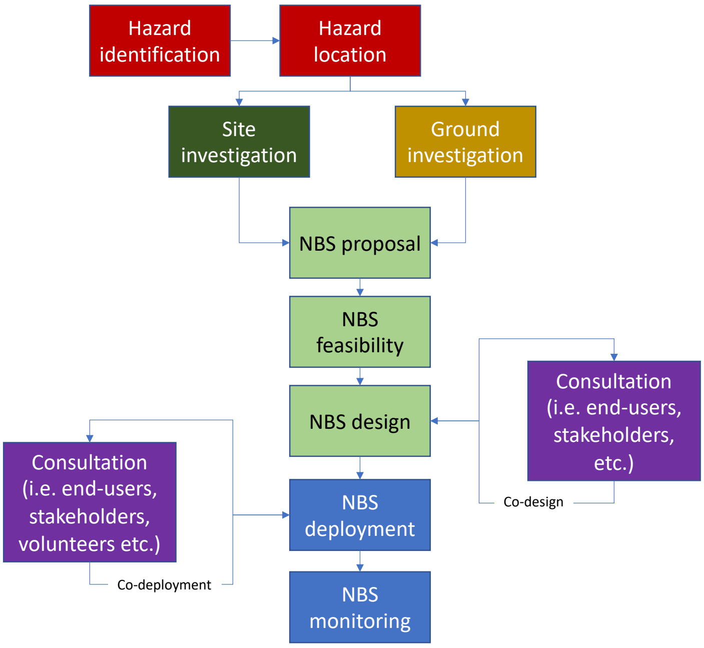


Figure 4. Conceptual model illustrating the steps to follow for the implementation and operationalisation of NBS at the OAL level.

4.1. Co-creation processes at OAL-UK

The co-creation process is a key objective of OPERANDUM. Successful co-creation involves the collaboration of local community stakeholders with policy makers, influencers and investors, alongside technical and scientific experts, to contribute knowledge and solutions to a shared problem. OPERANDUM partners have produced a Stakeholder Engagement Strategy and a Co-design Strategy to guide OAL teams through maximising the benefits of both the stakeholder engagement process, and the co-creation process; the latter can be seen in Figure 5.

At OAL-UK, GCU has been working through the co-creation processes that have been aligned with co-design and co-development, and preparing for co-deployment activities. While the process presents itself logically as linear, GCU's experience is that co-creation is iterative in nature. As the co-development and co-deployment phases progress, we will continue to engage with the stakeholders identified early in the co-design phase, reviewing these groups, their needs and requirements, and their potential level of involvement with the project. In addition, we will identify and connect with any new stakeholders who emerge through social, economic or ecological changes at the OAL.

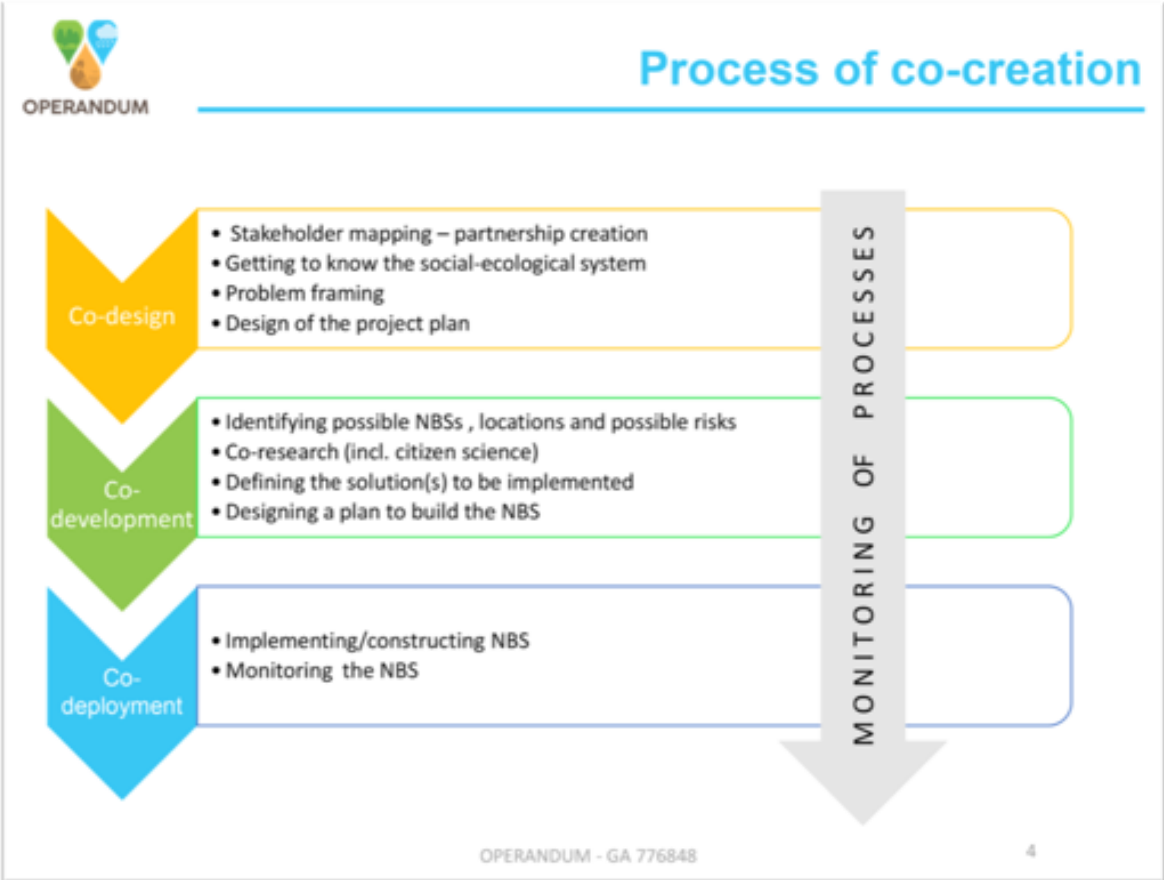


Figure 5 Process of co-creation developed through OPERANDUM Task 1.3 ("OALs co-design strategy within OPERANDUM Task 1.3 (p.4)", Soini, K. (LUKE), 1st Annual OPERANDUM meeting, European Cultural Centre of Delphi, 4-6 June 2019)

4.2. Co-Design processes at OAL-UK

At OAL-UK, GCU has been building and maintaining relationships with some local stakeholders since 2013, learning of needs, requirements and expectations through informal conversations. This provided a strong foundation for a formal stakeholder mapping exercise as described in the OPERANDUM stakeholder engagement and co-design strategies gathered in WP1 and WP8. The outcome of the stakeholder mapping exercise for OAL-UK is shown in Table 2. The stakeholder mapping exercise formally documented the local, regional and national groups who were already involved with the slope protection works, in addition to identifying groups that were not yet engaged but could be strong contributors to the work through their role in the social-ecological system in Catterline. The identified stakeholders were then each assigned two sets of "Interest" and "Power" scores: the first set for their current Interest-Power (Activity Period 1), and the second for the target Interest-Power by March 2020 (Activity Period 2), when the first co-deployment session is proposed to be held. These can be seen in Figure 6 and Figure 7. Through this exercise, stakeholders who we hoped to increase engagement with were prioritised, and relationship building activities were started.

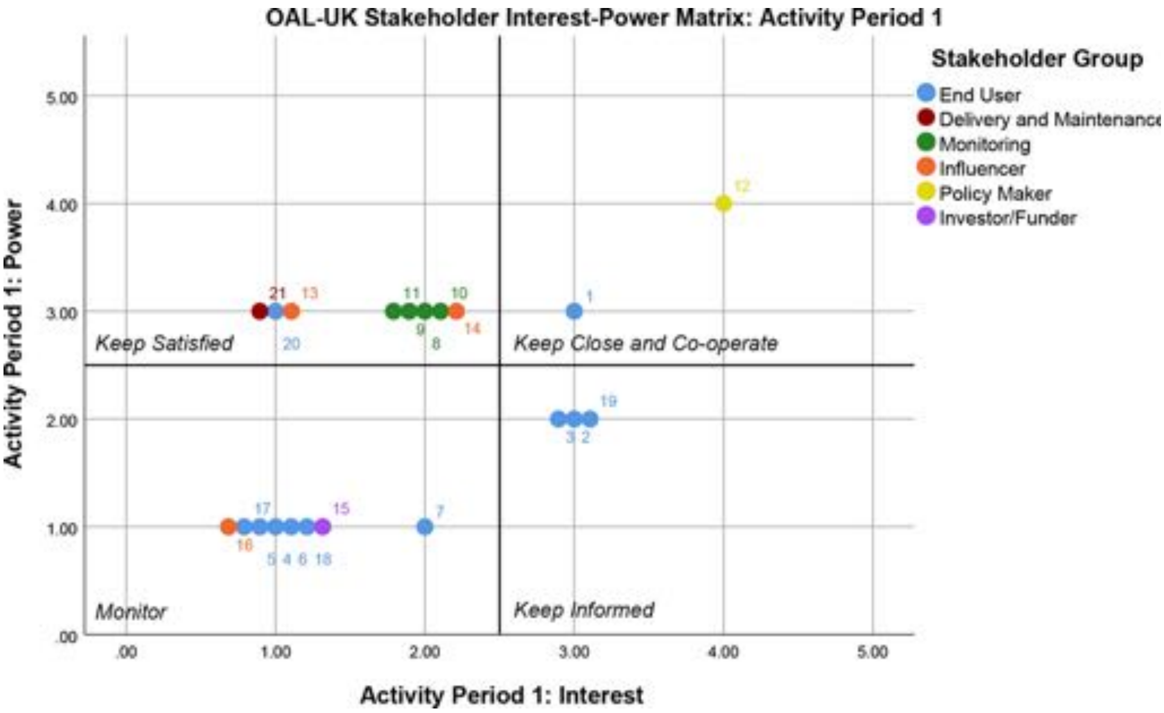


Figure 6 Current Interest-Power for OAL-UK Stakeholders

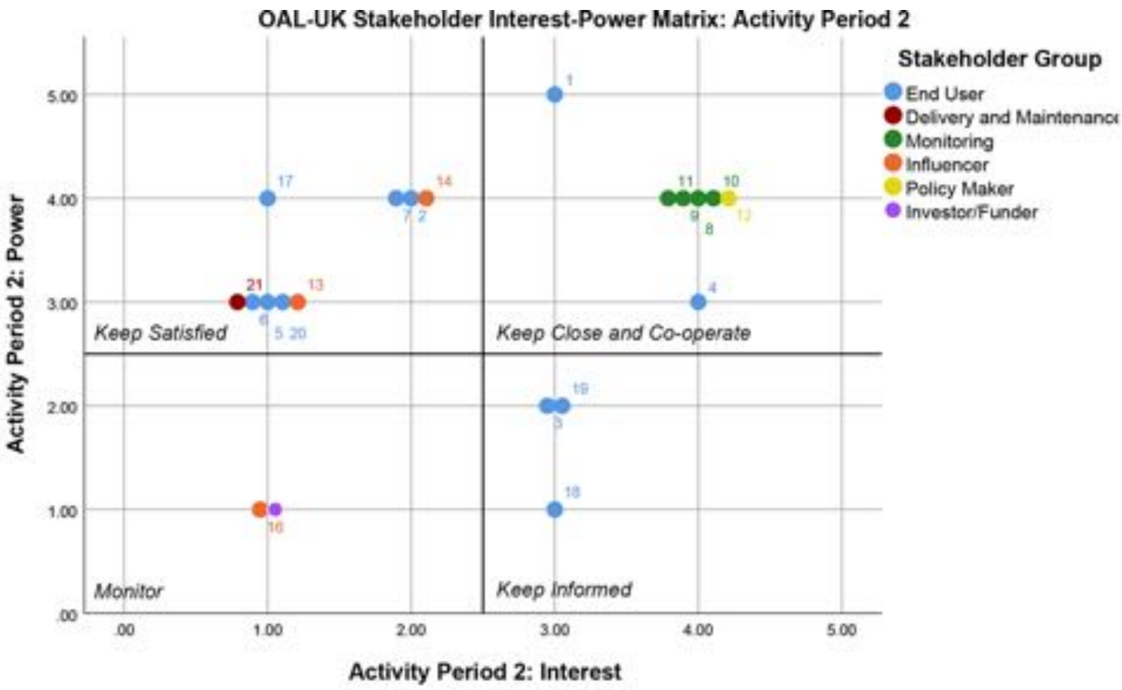


Figure 7 Target Interest-Power for OAL-UK Stakeholders

For example, with Catterline School, the head teacher was contacted via email and an in-person meeting for further discussion was arranged, focussing on opportunities to involve teachers and pupils in the OAL-UK in ways that complement their national curriculum requirements. In another example, Catterline Coastal Rowing Club was contacted, again initially by email. We then attended one of their regular rowing sessions in-situ at Catterline Bay, joining the rowers out on the North Sea and experiencing first-hand the way in which this group makes use of the coast and bay. This increased our capacity to understand how a significant weather event could negatively impact on the Club's ability to operate, as well as understanding the Club's perspectives on the positive aspects of the Bay as a place within their daily lives.

Table 2 OAL-UK stakeholders: identification, classification, mapping of needs, requirements and expectations

ID	Name	Stakeholder Group	Summary of needs, expectations and requirements
1	Catterline Braes Action Group	End user	Stabilisation of slope; protection of properties; protection of road access; natural aesthetic and materials; affordability
2	Catterline Residents	End user	Stabilisation of slope; protection of properties; protection of road access; natural aesthetic and materials; affordability
3	Farmers	End user	Flooding from burn; protection of farmland;
4	Catterline School	End user	Natural aesthetic; educational opportunities; citizen participation
5	Montrose Sub-Aqua Club	End user	Protection of road access; protection of property
6	Catterline Coastal Rowing Club	End user	Protection of road access; protection of property
7	Creel Inn	End user	Protection of road access; protection of property; natural aesthetic and materials
8	Aberdeenshire Council - Port	Monitoring	Evidence of performance and repeatability of solutions for coastal erosion and citizen participation, to inform policy and guidelines
9	Aberdeenshire Council - Transport	Monitoring	Evidence of performance and repeatability of solutions for coastal erosion and citizen participation, to inform policy and guidelines
10	Aberdeenshire Council - Flooding	Monitoring	Evidence of performance and repeatability of solutions for coastal erosion and citizen participation, to inform policy and guidelines
11	Aberdeenshire Council - Coastal	Monitoring	Evidence of performance and repeatability of solutions for coastal erosion and citizen participation, to inform policy and guidelines
12	SEPA	Policy maker	Evidence of performance and repeatability of solutions for coastal erosion and citizen participation, to inform policy and guidelines; Protection of biodiversity; natural aesthetic and materials
13	Stonehaven and District Community Council	Influencer	Evidence of performance and repeatability of solutions for coastal erosion and citizen participation, to inform policy and guidelines
14	Catterline, Kinneff and Dunnottar Community Council	Influencer	Evidence of performance and repeatability of solutions for coastal erosion and citizen participation
15	Windfarm Community Fund	Investor/funder	Value (economic); benefit to local community; Evidence of performance and repeatability on citizen participation
16	Woodlands Trust	Influencer	Evidence of performance and repeatability of using vegetation for stabilising/erosion control; evidence on citizen participation
17	Residents of neighbouring communities	End user	Stabilisation of slope; protection of properties; natural aesthetics and materials; evidence of performance and repeatability in their own areas

18	Tourists	End user	Protection of access road; natural aesthetic
19	Recreational bay users	End user	Protection of access road; natural aesthetic
20	Catterline braes landowner	End user	*n/a* **
21	Scottish Water	Delivery and maintenance	*n/a* **
22	GCU OPERANDUM *	Monitoring	Evidence on scientific, ecological and socio-economic benefits of NbS; evidence on citizen participation; scientific publication and future research grants; collaboration in operationalisation of NbS
23	NATURALEA *	Designer	Evidence on scientific and ecological benefits of NbS for informing standards and design; citizen participation; collaboration in operationalisation of NbS

** Party not included on IvP matrices as they are part of OAL-UK/OPERANDUM team*

*** Party has waived involvement/has been uncontactable. As legal owners of infrastructure involved in work, a relatively high "Power" is still given.*

Identifies the key stakeholders to increase engagement with, approaching proposed March 2020 co-deployment workshop at OAL-UK

4.3. Co-development process at OAL-UK

Stakeholders were introduced to OPERANDUM and NBS through a series of public meetings held within the OAL, where GCU presented the aims and intentions of the project. The first of these meetings presented the ways in which NBS are relevant to OAL-UK, and how NBS can address the hazards on the slopes and the concerns of the stakeholders. The meeting also allowed comment, feedback and discussion on the OPERANDUM project generally. From this, formal proposals for all NBS options that were technically feasible at OAL-UK were developed by GCU; these, and the locations where they could be implemented, were presented at a second public meeting. A survey was distributed that captured which NBS were preferred, and allowed for positive and negative feedback on the proposals. The community stakeholders were also able to state a collective preference for the first co-deployment session to be rescheduled from its originally proposed time in Autumn 2019, to March 2020 in order to avoid clashes with existing community events. The NBS showcased at these public meetings and their selection rationale is described in Section 5.

4.4. Co-deployment process at OAL-UK

Finally, a co-deployment workshop has been proposed for March 2020, that will bring community stakeholders together with local authorities and professionals interested in NBS, to introduce them to the theory behind NBS and how it can be applied in OAL-UK. The workshop participants will then, in groups lead by NBS experts, take part in the physical construction of the NBS over two days. In addition to the actual NBS deployment the workshop will create connections between local community stakeholders and external stakeholders with a shared NBS interest, and increase capacity for both groups to advocate for the mitigation of hydro-meteo hazards using NBS. The stakeholder engagement and co-creation processes will continue to be applied iteratively where necessary through the co-deployment and monitoring phases.

5. Projected NBSs at OAL-UK

GCU, in partnership with Naturalea, is looking into the implementation of 8 original NBSs against shallow landslides and surface erosion at OAL-UK. The selection of the different NBSs and actions was done in agreement with the conceptual model shown in Fig. 4. The projected NBSs are classified as soil and landscape solutions (Keestra et al., 2018; Sahani et al., 2019) and they comprise both hybrid and green NBS (Debele et al., 2019). The selected NBSs will be distributed over 11 different actions (Fig. 5). These will be deployed at different locations within the OAL to explore the performance of the projected NBSs under changing edaphological and topographical conditions (e.g. slope, aspect, curvature, etc) with the aim of upscaling the planned NBSs in the future. In addition, each planned NBS will be vegetated using different plant species combinations and densities to explore performance differences in the mid and long terms with respect to plant diversity and establishment. The 11 NBS actions are planned to be deployed along the beach access road within Catterline Bay. With this, our intention is to create an open-air NBS exhibition which both residents and tourists will have the opportunity to interact with along the walk to the beach. This will enable the visitors to gain insight into NBSs, overall promoting and improving their public acceptance and perception. A brief description of each NBS is provided below. Illustrations and drawings for the planned NBS are shown in Section 6.

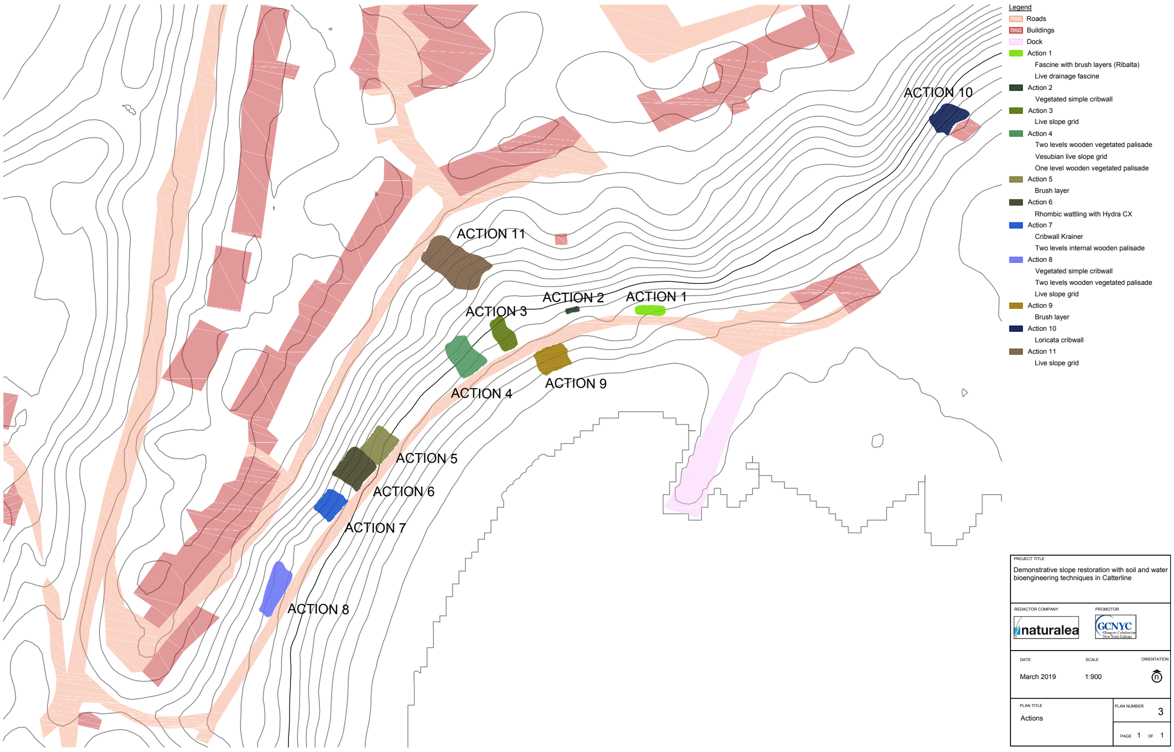


Figure 8. Identified NBS at OAL-UK and location within the OAL on the basis of detection and identification of zones prone to shallow landslides and surface erosion. See Gonzalez-Ollauri and Mickovski (2017b).

5.1. Brush layers

A brush layer consists of a series of steps excavated on the slope, which are then reinforced with plant cuttings, bundles, stacks, and loose earth materials. The aim of a brush layer is to reduce the slope gradient as in terraced systems while ensuring long-term stability and resilience with the establishment of a dense vegetation cover. This technique is applied to slopes with a gradient less than 40°. Branches and cuttings from plant species with the ability to propagate from stems and cuttings (e.g. willow) are placed crosswise on terraces of at least 50 cm in width and with a counter-fall towards the main slope. The branches should cover at least 50% of the area and are filled up with material excavated from the terrace above. To secure the counterscarp from fallings, the branches are placed onto the backwards incline base; then the filling operation is continued.

5.2. Live fascine

A live fascine is a technique that consists in the installation of faggots made of bushes and tree branches of riparian species that are able to reproduce from branches and cuttings (i.e. vegetative propagation). The brushwood faggot or fascine is built by disposing all the branches in the same direction. With this technique, we can use vegetal waste coming from the implementation of other bioengineering techniques, in which bigger bushes and logs are used. The material used to build the fascines is, generally, the leftovers from the preparation of live stakes. It is important that some of the employed branches are at least 3cm wide, as the wider sections are more prone to regrow, while the thinner branches will provide a structural function, retaining soil until a resilient root tissue is fully grown. It is important and preferable to use local species, as well as building the fascines during the dormant season. In zones with harsh climatic conditions, these structures are established by burying completely a first layer of fascines. Then, one or more layers can be added depending on the zone's conditions and the erosion control needs. When more than two layers are installed, the technique is called *Fascine with brushlayers Ribalta*.

5.3. Fascine with brushlayers

This technique is used with the objective to apply an immediate protection of the slope toe. It uses different stratums overlapped by live fascines. These are placed longitudinally at the slope or terrace toe combined with live stakes, normally of willow, placed transversely at the edge of the intervention. Fascine with brushlayer enables the installation of 3+ levels/terraces of fascines, while two levels are only possible with the technique described in 6.2.

5.4. Live cribwall

A live cribwall is a gravity wall made of a cellular structure with logs and living stakes or plants in container with the objective that the future development of the plant substitutes the logs structure following its natural degradation or decay. This technique is used as a retention wall in the stabilisation of slopes with gradients up to 60°.

The cribwall structure is made of timber logs (i.e. logs of peeled conifer, chestnut...) deployed perpendicularly and horizontally with respect to the slope. The space between the logs is filled with compacted earth materials and living stakes, cuttings or plants in container are planted on the front part in high density to retain and reinforce the soil materials. Plant fascines can be also deployed within the front part, which will contribute to retain moisture and foster the establishment of vegetation within the cribwall. The structural logs are secured with nails or steel bars to ensure that the cribwall structure works as a block. A minimum amount of anchorage points is advisable, as places in which nails are installed are prone to rapid degradation.

Live cribwalls can use any type of wood, yet hardwoods with a slow degradation are recommended, as enough time for the establishment of vegetation within the cribwall must be allowed. The diameter of the logs can be highly variable. We recommend the use of logs with diameters comprised between 20 and 30 cm in diameter. It is worth noting that in many instances, timber logs are supplied/sourced with heterogeneous and uneven diameters. To circumvent this issue, it is important to establish even horizontal levels. The live cribwall should have a gentle slope towards the inner part. At the inner cribwall section, the perpendicular logs have a very important anchorage role to the original slope section. The cribwall structure always needs a certain foundation depending on its location and the load it is supposed to stand. In water courses, for instance, it is advisable to protect the cribwall base with stones, rock roll gabions or resistant materials and to level the base below the transitory erosion level. Part of the cribwall foundation must be directly linked to the upper structure and must allow root colonisation. The cribwalls should not have more than 2 m in height. If the height of the slope to protect is higher, a system of cribwalls deployed in terraces should be considered.

5.5. Slope lattice

A slope lattice is a structure made by the union of timber logs deployed perpendicular to each other, creating a grid or lattice structure seated on the slope to be protected. The structural logs are secured to the ground with nails. A minimum amount of anchorage points is advisable, as places in which nails are installed are prone to rapid degradation. The entire slope lattice structure is secured to the ground with steel nails, anchors with wooden sticks anchored to the ground, which will reinforce the soil mechanically over time. The internal part of the slope lattice is filled with earth materials, rooted plants, cuttings and seeds in high density. Slope grids can be deployed for the protection of relatively stable slopes with severe problems of soil consolidation and on slopes with a slope gradient greater than 45-50^{o}. The number of horizontal logs is calculated in relation to the slope and cohesion of the soil. As with other NBS, the evolution of the structure depends on the plant species, so plant selection is paramount.

5.6. Live palisade

Live palisades are vertical or slightly inclined wooden structures used to retain the ground on embankments and at slope toes. Live palisades tend to increase the power of the soil or its inner depth. When the wooden structure decays, vegetation roots will reinforce the non-stabilised interspaces of the palisade. This structure is formed by living poles or stakes, which are driven into or buried in the ground horizontally with respect to the slope or wall, forming an array of stakes with gaps in between equal in width to the diameter of the employed stakes. As the structure is built, it is backfilled progressively with soil to level it up the top part of the structure. The latter step is not needed when the palisade is designed for retaining sediment naturally contained in the runoff. Wooden stakes of 8 to 12 cm in diameter are used as vertical posts. These are deployed with a space of 1 to 1.5 meters, depending on the amount of plant material available. After backfilling the wooden structure, it is convenient to sow seeds of native herbaceous or planting native shrubs.

5.7. Loricata cribwall

The Loricata cribwall is a constructive technique based on the creation of a wooden, durable structure that maintains its structure for a large period of time until the vegetation cover develops. It comprises a metal frame holding a series of frontal logs deployed horizontally. The structure is anchored to the ground through a central metallic piece located at the gravity centre. Using basic principles of structural mechanics, the standing force and length of the structure used to anchor the whole structure at the gravity centre can be easily determined. The frontal appearance of a Loricata cribwall is very similar to any cribwall. It can be easily vegetated for landscaping purposes but the stability of the structure no longer depends on the vegetation. The structure has a known, stable and permanent resistance from the moment of its construction and allows the vegetation to develop without any impediment. It should be noted that this system avoids drilling holes in the wooden logs, which grants a longer durability of the logs. In addition, loricata cribwalls are low cost, quick to install and provide an immediate stabillisation effect.

5.8. Live pole drain

A live pole drain (LPD) is composed of a bundle of cuttings and fascines placed horizontally on the ground and oriented in the downslope direction (Fig. 6). Live drains thus facilitate the movement of water off the slope. Hence, live drains can provide ground stability where excess moisture has created instability. Live drains may also allow for vegetation establishment, by reducing earth slumping as a result of improved drainage and root reinforcement. Moreover, the vegetation slows down water movement, reducing erosion, and preventing gully formation. The live drain should comprise a main or principal drainage path in along the flow path to which drainage branches flow into. The main drainage path and branches should be built from ca. 20-30 cm cylindrical bundles of live cuttings and fascines. The main drainage path should be oriented in the direction of the slope and the branches or lateral drain fascines should be deployed in a way that flow into the main drainage is ensured. The lateral drain fascines should be smaller than the main drainage cuttings (e.g. 10-20 cm in diameter). In some instances, it is advisable to cover the live pole drain with earth materials to ensure an adequate contact of the employed plant materials with the soil, promoting the development of roots.

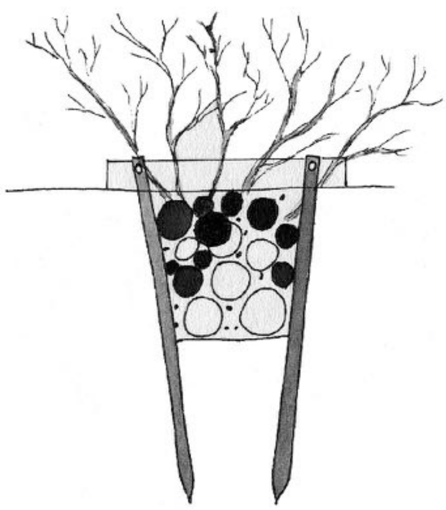


Figure 9. Illustration of a live pole drain. Source: Norris et al. (2008).

5.9. Krainer cribwall

This technique has the same functionality as the live cribwall (Section 4.4) but it is employed for the protection ofsteeper slopes withhigher soil surcharge. This can be achieved by deploying a second line of logs within the cribwall structure. The second line of logs is located behind the first one horizontally and against the slope gradient.

5.10 Live ground anchors

Earth anchors in combination with substrate+seed bags can be rapidly deployed in most displaceable ground conditions. This type of NBS can improve the stability conditions of the slope at the same time that can lead to a fast development of a vegetated ground cover able to prevent erosion. This NBS should be deployed at locations presenting steep slopes and clear landslide and erosion signs in which the implementation of other mechanical plant operations are not feasible due to the topographical and ground conditions. Earth anchors can be deployed with the use of portable, manual augering equipment and usually require low to no maintenance at locations free from severe coastal erosion episodes. With this technique bags containing earth materials and seeds are filled and deployed on the ground surface attached to the anchors cap. Earth materials should be chosen according to the soil type present at the OAL. If possible, earth materials from landslide deposits can be employed to fill the bags to be seeded. The addition of organic substrates and fertilisers will aid in the germination and development of the seeded vegetation. Plant materials should be selected in agreement with the environmental conditions of the OAL. In general, native fast growing and frost resistant plant species should be preferred. The intervention can be finished with the deployment of a synthetic geogrid or an organic blanket made from coir.

6. Botanical characteristics of the projected NBS at OAL-UK

The proposed original NBS at OAL-UK will employ soil bioengineering techniques contemplating the use of local and pioneer plant species. It is worth noting that pioneer plant species have the capacity to colonise degraded and disturbed land (e.g. landslide-prone landscapes). Yet, not all plant species have these mechanical capacity to stabilise slopes and provide effective erosion control. As a result, careful plant selection is mandatory to ensure intervention success. Plant species useful in soil bioengineering should present the following features:

- Adventitious root emission capacity
- Rooting ability of cuttings and branches
- Sufficient Mechanical tensile strength of roots and shoots
- Resistance to falling stones
- Dense canopy to intercept rainfall and foster evapotranspiration
- Survival capacity after planting
- Resistance to soil wet conditions and good water uptake capacity
- Mechanical tensile strength
- Soil consolidation
- Ground soil improvement
- Aboveground architectural traits that reduce the concentration of precipitation around the tree bole (i.e. stemflow).
- Resistance to overturning and toppling
- Balanced allometric relationship between above and belowground plant parts

Willow species have been traditionally used in soil bioengineering interventions due to their fast-growing nature, to their outstanding ability to propagate from shoots and branches, to their adaptation to wet soils and environments, and to their water (and pollutants) uptake capacity. The presence of willow species such as *Salix viminalis* at OAL-UK make willow a great species candidate to be employed within the planned interventions at the OAL. In addition, there is clear supporting evidence suggesting that willow leads to increased slope stability at the OAL (e.g. Gonzalez-Ollauri and Mickovski, 2017). Other local candidate plant species to be employed within the planned NBS interventions are: sycamore (*Acer pseudoplatanus* L.), silver birch (*Betula pendula*), wild cherry (*Prunus* sp.), gorse (*Genista falcata* L.), broom (*Cytisus scoparius*), hawthorn (*Crataegus monogyna* L.) together with some pioneer herbs such as red campion (*Silene dioica* L.), blue fleabane (*Erigeron acris*) and clover (*Trifolium sp.*), which are expected to colonise the intervention site spontaneously. Plant species from which fruit and fibre can be retrieved could be interesting, too, yet our aim is to employ plant species that can be sourced within the OAL. A brief description for each plant species is provided below.

6.1. Basket willow (Salix viminalis L.)

It is a multistemmed shrub growing to between 3 and 6 m. It has long, erect, straight branches with greenish-grey bark. The leaves long and slender, 10–25 cm long but only 0.5–2 cm broad. The flowers are catkins, produced in early spring before the leaves; they are dioecious, with male and female catkins on separate plants. It is commonly found by streams and other wet places. Along with other related willows, the flexible twigs (called withies) are commonly used in basketry, giving rise to its alternative common name of "basket willow". *Salix viminalis* is a known hyperaccumulator of heavy metals and other pollutants.

6.2. Sycamore (*Acer pseudoplatanus* L.)

It is a large deciduous, broad-leaved tree, tolerant of wind and coastal exposure. It is native to Central Europe and Western Asia. The sycamore establishes itself easily from seed. The sycamore can grow to a height of about 35 m (115 ft) and the branches form a broad, rounded crown. The bark is grey, smooth when young and later flaking in irregular patches. The leaves grow on long leafstalks and are large and palmate, with 5 large radiating lobes. The flowers are greenish-yellow and hang in dangling flowerheads called panicles. They produce copious amounts of pollen and nectar that are attractive to insects. It readily invades disturbed habitats. It is tolerant of a wide range of soil types and pH, except heavy clay, and is at its best on nutrient-rich slightly calcareous soils. The roots of the sycamore form highly specific beneficial mycorrhizal associations with the fungus Glomus hoi which promotes phosphorus uptake from the soil. Sycamores make new growth from the stump or roots if cut down and can therefore be coppiced to produce poles and other types of small timber. Sycamore is planted in parks for ornamental purposes, and sometimes as a street tree, since its tolerance of air pollution makes it suitable for use in urban plantings.

6.3. Silver birch (Betula pendula Roth)

Tree species native to Europe and parts of Asia. The silver birch is a medium-sized deciduous tree, typically reaching 15 to 25 m height, that owes its common name to the white peeling bark on the trunk. The twigs are slender and often pendulous and the leaves are roughly triangular with doubly serrate margins and turn yellow in autumn before they fall. The flowers are catkins and the light, winged seeds get widely scattered by the wind. The silver birch is a hardy tree, a pioneer species, and one of the first trees to appear on bare or fire-swept land. The silver birch has an open canopy which allows plenty of light to reach the ground. This allows a variety of mosses, grasses and flowering plants to grow beneath which in turn attract insects. Successful birch cultivation requires a climate cool enough for at least the occasional winter snowfall. As they are shallow-rooted, they may require water during dry periods. They grow best in full sun planted in deep, well-drained soil.

6.4. Hawthorn (Crataegus monogyna L.)

It is a native shrub to temperate regions of the Northern Hemisphere in Europe. Mostly growing to 5–15 m tall, with small pome fruit and (usually) thorny branches. Hawthorns provide food and shelter for many species of birds and mammals, and the flowers are important for many nectar-feeding insects. Many species and hybrids are used as ornamental and street trees. The common hawthorn is extensively used in Europe as a hedge plant. Hawthorns are among the trees most recommended for water conservation landscapes. Hawthorn can be used as a rootstock in the practice of grafting. Although it is commonly stated that hawthorns can be propagated by cutting, this is difficult to achieve with rootless stem pieces. The wood of some *Crataegus* species is hard and resistant to rot.

6.5. Broom (Cytisus scoparius L.)

it is a perennial leguminous shrub native to western and central Europe. Plants of *C. scoparius* typically grow to 1–3 mtall, rarely to 4 m, with main stems up to 5cm. The shrubs have green shoots with small deciduous trifoliate leaves 5–15 mm long, and in spring and summer are covered in profuse golden yellow flowers 20–30 mm from top to bottom and 15–20 mm wide. *C. scoparius* is found in sunny sites, usually on dry, sandy soils at low altitudes, tolerating very acidic soil conditions.

6.6. Gorse (Ulex europaeus L.)

It is a perennial leguminous shrub native to much of western Europe, where it grows in sunny sites, usually on dry, sandy soils. It is also the largest species, reaching 2–3 metres. Gorse thrives in poor growing areas and conditions including drought; it is sometimes found on very rocky soils, where many species cannot thrive. Moreover, it is widely used for land reclamation (e.g., mine tailings), where its nitrogen-fixing capacity helps other plants establish better.

Gorse is a valuable plant for wildlife, providing dense thorny cover ideal for protecting bird nests. Gorse readily becomes dominant in suitable conditions, and where this is undesirable for agricultural or ecological reasons control is required, either to remove gorse completely, or to limit its extent. Gorse stands are often managed by regular burning or flailing, allowing them to regrow from stumps or seed.

6.7. Blue fleabane (Erigeron acris L.)

Blue fleabane is a common native annual or occasional perennial growing to a height of about 20 – 50cm. Blue fleabane is a plant of skeletal environments on well-drained neutral or calcareous soils particularly on warm southing facing slopes. Habitats include sand dunes, quarries, waste areas, walls and rock outcrops. Grows readily from seed sown at any time of the year.

6.8. Red campion (Silene dioica L.)

It is a herbaceous flowering plant in the family Caryophyllaceae, native throughout central, western and northern Europe, and locally in southern Europe. It is a biennial or perennial plant, with dark pink to red flowers, each 1.8-2.5 cm across. The flowering period is from May to October. The plant grows to 30–90 cm, with branching stems. Red campion grows in roadsides, woodlands, and rocky slopes. It prefers to grow on damp, non-acid soils.

6.9. Clover (Trifolium spp.)

It belongs to the legume or pea family Fabaceae. The genus has a cosmopolitan distribution with highest diversity in the temperate Northern Hemisphere. They are small annual, biennial, or short-lived perennial herbaceous plants with the ability of fixing atmospheric nitrogen.

7. Technical specification of the planned NBS actions at OAL-UK

7.1. Action 1: Stabilisation of slope's toe with brush layers and drainage and stabilisation of the upper slope section with live fascine

The zone where this action has been planned presents a slope gradient comprised between 40 and 55°. This zone has suffered a landslide event in the past (Fig. 7). At present, an active drainage system consisting of a corrugated pipe collects surface water from the upper slope. The water collected by the pipe then flows into a gravel channel located in the internal margin of the access road to the beach (Fig 8). Soil wetness is evident in this zone, which encourages further slope movement and surface erosion. Thus, the zone must be drained to ensure adequate stabilisation, for which a life pole drain would be effective (Fig. 9). The slope's toe also presents clear signs of instability. Yet, the slope's toe has dryer soil conditions than the upper counterpart. The dimensions and access to the slope's toe make feasible the implementation of a brush layer (Fig. 10). Both interventions are intended to work complementary. On the one hand, the brush layer intended for the slope's toe will confer stability to the slope system by reducing the slope gradient and by fostering the development of a vegetation mat contributing to the mechanical and hydrological stability of the slope forming materials. On the other hand, the live fascine intended for the upper slope part will collect and withdraw surface water. This will help to improve the hydromechanical stability of the zone in which the live fascine is deployed at the same time that reduces the amount of water received by the slope's toe. As a result, the live fascine will also contribute towards the stabilisation of the slope's toe.

Figure 10. Zone affected by shallow landslides at OAL-UK.

Figure 11. Location and layout for Action 1.

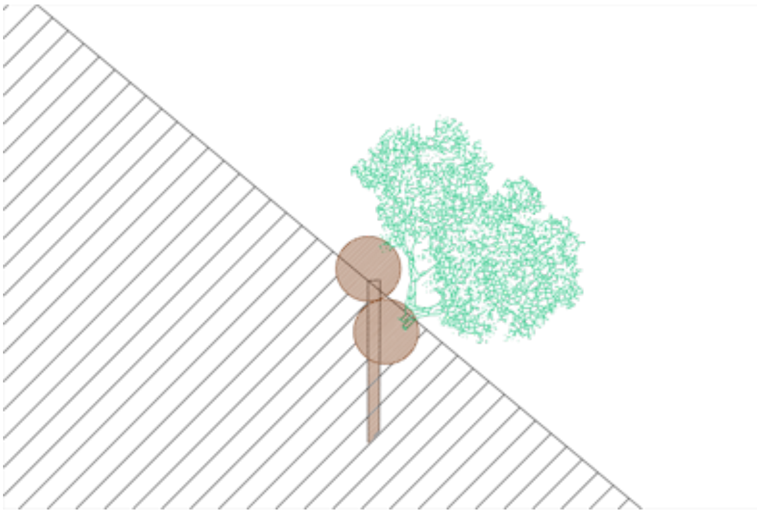


Figure 12. Profile view for the live pole drain planned in Action 1.

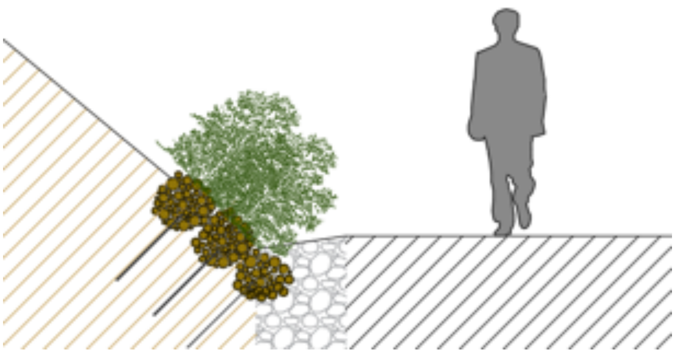


Figure 13. Profile view for the fascine combined with brush layer planned in Action 1.

Table 3. Characteristics of Action 1.

Description	Dimensions
Stretch length	9 m
3 levels fascine with brush layers (Ribalta)	11 m
2 lines of live drainage fascine. The upper one of 4 m of length can be made by shrub material of pruning remains and the other one measures 6m.	10 m

7.2. Action 2: Simple Live cribwall to stabilise and protect a slope crest section

The zone in which action 2 (Fig. 5) is planned shows clear evidence of slope failure. This is clearly seen in the lower slope gradient of the bottom section with respect to the top (Fig. 11), as a result of the accumulation of sliding soil materials. A live cribwall (Fig. 12) is intended in this zone. A live cribwall consists of a wooden frame built with superposed timber logs (generally peeled pine). To form the cribwall structure, the timber logs are deployed orthogonally (Fig. 12). Three rows of logs are deployed and anchored facing the slope, while another three rows of logs are deployed against the slope gradient. The logs deployed against the slope gradient are nailed to the logs inserted into the slope. The inner part of the frame is then backfilled with earth and plant materials. As the timber logs within the frame structure decay, the action of the established vegetation will take over, conferring mechanical and hydrological stability to the intervention in the long term. To encourage the long-term stability of this intervention further, the soil materials located at the crest of this section are removed and used to fill the cribwall structure (Fig. 12). The designed cribwall is intended to be 1.4 m high.

Figure 14. Location and layout for Action 2.

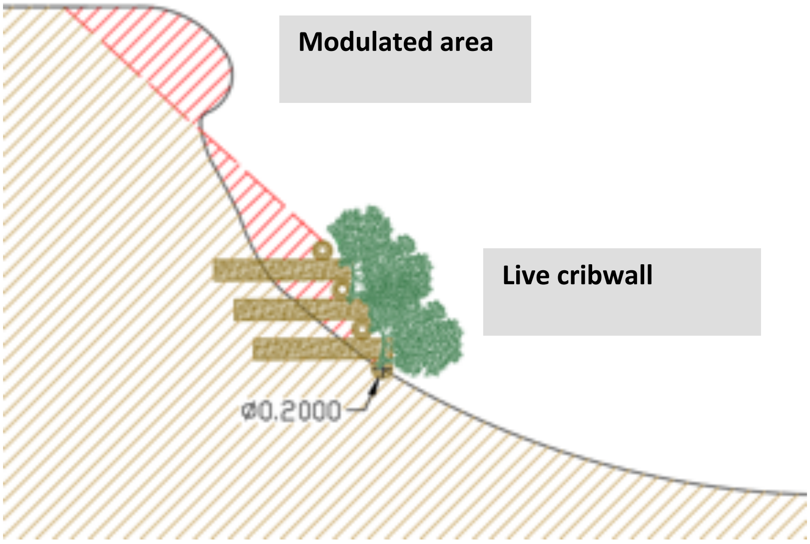


Figure 15. Profile view for the simple live cribwall planned in Action 2.

Table 4. Plant species and individuals distribution envisaged for the simple live cribwall planned in Action 2.

	1st level	2nd level	3rd level	Units/individuals
Hawthorn (*Crataegus monogyna*)		6		6
Boom (*Cytisus scoparius L.)*			6	6
Gorse (*Ulex europaeus L.)*		5	5	10
Basket willow (*Salix viminalis L.*)	10	5	5	20
Sycamore (*Acer pseudoplatanus L.*)	6			6
Units/individuals	16	16	16	48

Table 5. Characteristics of Action 2.

Description	Dimensions
Live cribwall (1,4m tall)	6 m
Plantation of vegetation in forestry tray	48 un
Plantation of Hawthorn (Crataegus monogyna)	6 un
Plantation of Broom (Cytisus scoparius L.)	6 un
Plantation of Gorse (Ulex europaeus L.)	10 un
Plantation of Basket willow (Salix viminalis L.)	20 un
Plantation of Sycamore (Acer pseudoplatanus)	6 un

7.3. Action 3: Slope lattice

Action 3 (Fig. 5) is intended to stabilise a slope section prone to failure or instability but that presents deeper soil materials (Fig. 13). A slope lattice (Figs. 14-16) acts like a wooden skin and it is comprised by a series of timber logs deployed orthogonally with respect to each other and nailed, creating a grid or lattice that it is then installed on the slope and backfilled with earth and plant materials. The idea is to build a temporal structure that will provide support and stability to the slope section where it is deployed until vegetation thrives and takes over – counteracting the effect from the decay of the lattice frame. It is worth noting that the stable conditions created within the structure will also encourage vegetation establishment and development. Slope lattices present the limitation of having to be built in agreement with the slope gradient. To overcome this limitation, two lattice sections will be deployed as part of Action 3 (Fig. 13). Further details on slope lattices are provided in Figs. 14-16.

Figure 16. Location and layout of Action 3.

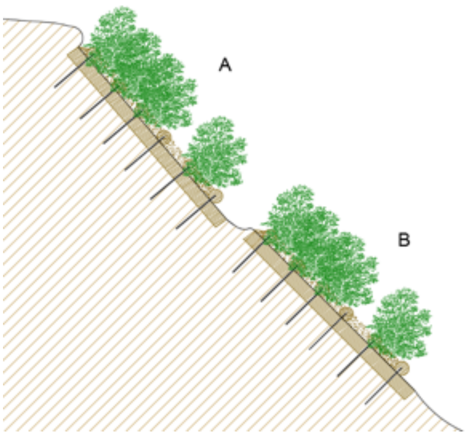


Figure 17. Profile view of the slope lattice planned in Action 3.

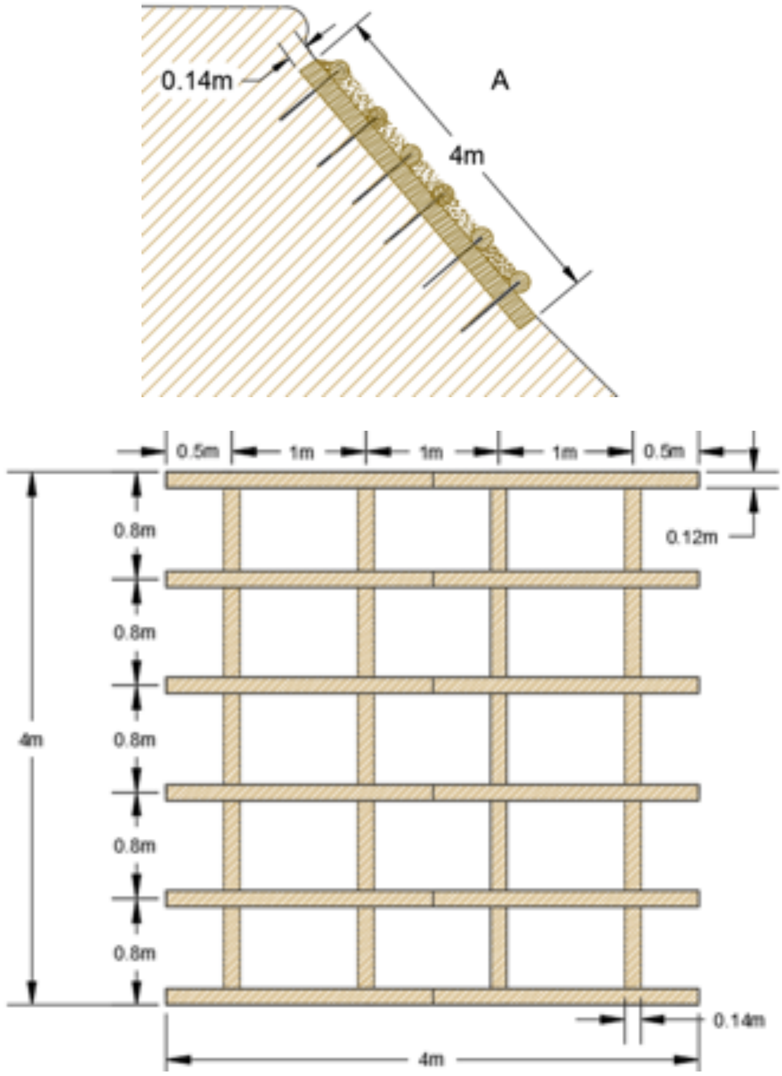
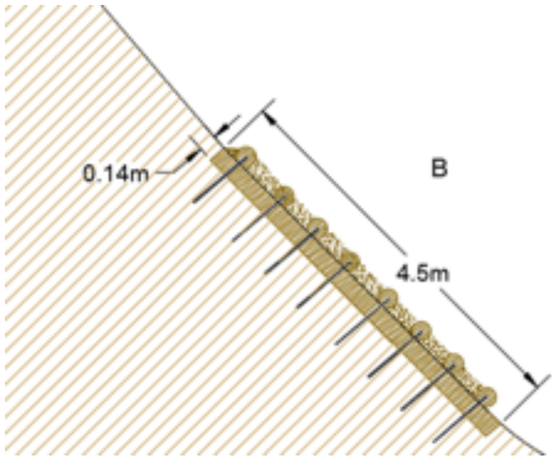


Figure 18. Profile and plan view for the slope lattice A planned in Action 3.

I

Table 6. Plant species and individuals distribution envisaged for the slope lattice planned in Action 3.

	1st level	2nd level	3rd level	4th level	5th level	6th level	Units/individuals
Hawthorn (*Crataegus monogyna*)	5	5		5			15
Boom (*Cytisus scoparius L.*)					3	5	8
Gorse (*Ulex europaeus L.)*			5		5	3	13
Basket willow (*Salix viminalis L.)*	5	5	5	5	2	2	24
Units/individuals	10	10	10	10	10	10	60



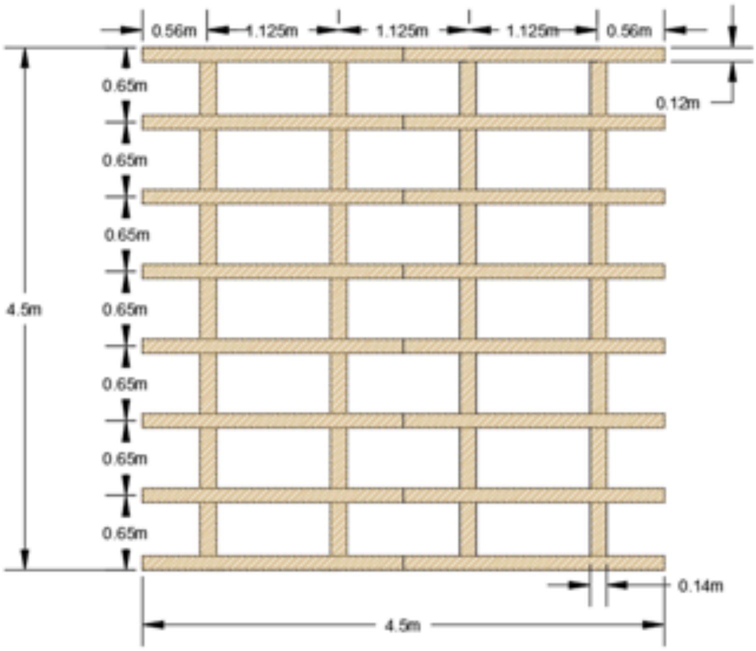


Figure 19. Profile and plan view for the slope lattice B planned in Action 3.

Table 7. Plant species and individuals distribution envisaged for the slope lattice B planned in Action 3.

	1st level	2nd level	3rd level	4th level	5th level	6th level	7th level	8th level	Units/individuals
Hawthorn (*Crataegus monogyna)*		6	6	6					18
Boom (*Cytisus scoparius L.*)					3	3	6	6	18
Gorse (*Ulex europaeus L.)*					6	6	3	3	18
Basket willow (*Salix viminalis L.)*	12	6	6	6	3	3	3	3	42
Units/individuals	12	12	12	12	12	12	12	12	96

Table 8. Characteristics of Action 3.

Description	Measurements
Live slope grid on the bottom de 4,5 x 4,5 m	1 un
Live slope grid on the top de 4 x 4 m	1 un
Plantation of vegetation in AF (Slope grid A)	60 un
Plantation of Hawthorn (Crataegus monogyna)	15 un
Plantation of Broom (Cytisus scoparius L.)	8 un
Plantation of Gorse (Ulex europaeus L.)	13 un
Plantation of Basket willow (Salix viminalis L.)	24 un
Plantation of vegetation in AF (Slope grid B)	96 un
Plantation of Hawthorn (Crataegus monogyna)	18 un
Plantation of Broom (Cytisus scoparius L.)	18 un
Plantation of Gorse (Ulex europaeus L.)	18 un
Plantation of Basket willow (Salix viminalis L.)	42 un

7.4. Action 4: Live palisade and Vesubian slope lattice

Action 4 (Fig. 5) will strive to stabilise two different slope sections (Fig. 17). To do so, a combination of live palisades and Vesubian-type slope lattice are intended for the slope's toe and crest, respectively. The selection of these techniques is done on the basis of the dimensions of the slope sections to be stabilised. The slope's toe in this slope section (Fig. 17) presents is wider than the upper slope zone. The slope's toe zone shows signs of soil materials accumulation. The upper slope part shows signs of sliding events and landslide scars are visible (Fig. 17). Due to the differences in terms of the geotechnical activity of this slope section, it is advisable to deploy a flexible structure at the toe (i.e. prone to resist less geotechnical activity) and a more stiff/rigid structure at the top.

A live palisade can be defined as a wooden barrier comprising a series of timber logs or thick branches deployed horizontally and attached to the ground with stacks or corrugated bars. In some instances, thick branches with the ability to resprout (e.g. willow, maple) are used as materials to provide further stability to the structure. Once the main structure of the palisade is built, the inner part is backfilled with earth and plant materials. The main role of the palisade is to collect eroding soil materials which will consolidate and serve as new substrate for the establishment and development of a vegetation cover. In the long term, the live palisade will provide mechanical and hydrological stability to the slope's toe. The live palisade designed for Action 4 comprises three different steps as shown in Fig 18. The lower step comprises two levels while the upper steps comprise one level.

The Vesubian slope lattice (Figs. 19-20) is a more stable structure than a simple slope lattice (see Action 3; Section 6.3) but easier to deploy than live cribwalls (see Action 2). However, the idea behind Vesubian slope lattice is the same as in the other soil bioengineering techniques described in previous sections – i.e. vegetation will provide soil reinforcement and future stability. A Vesubian slope lattice is comprised by a grid of timber logs deployed and nailed orthogonally. The difference with respect to the slope lattice is that the Vesubian slope lattice is anchored to the soil with logs of wood (Figs. 19-20).

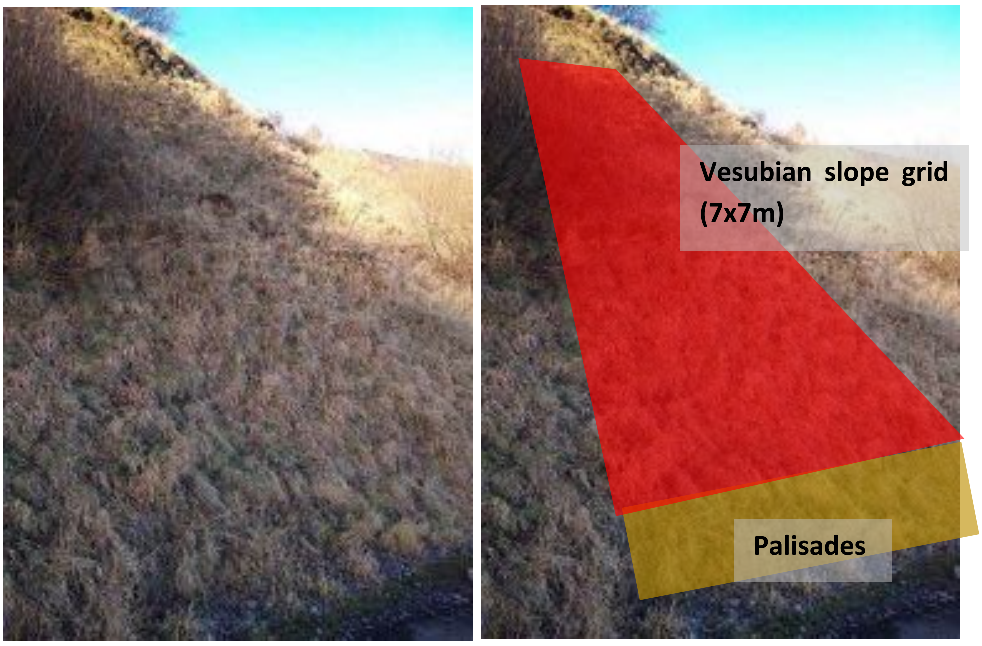


Figure 20. Location and layout for Action 4.

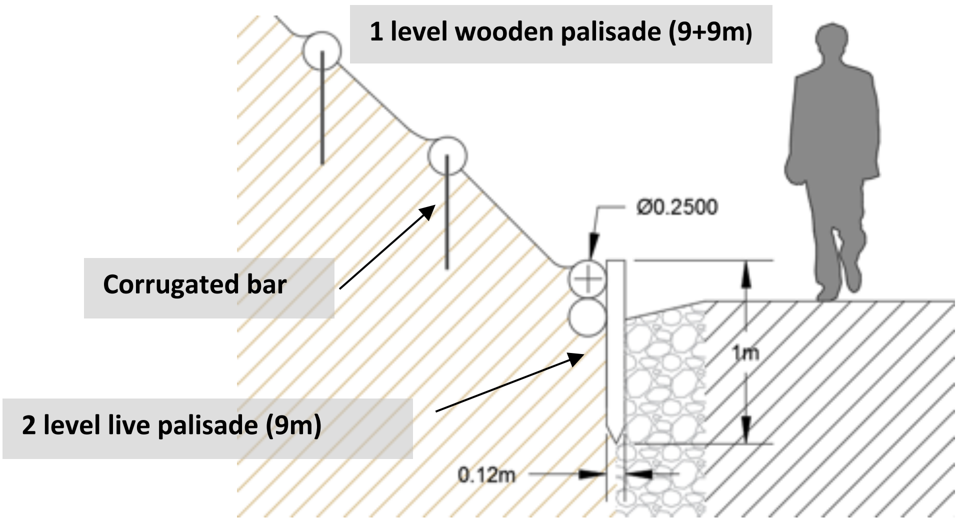


Figure 21. Profile view for the live palisade planned in Action 4.

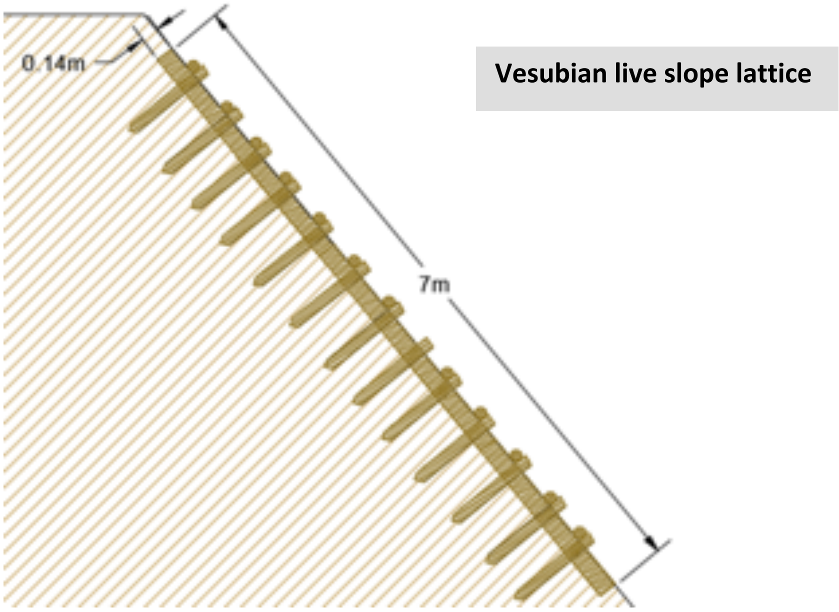


Figure 22. Profile view for the Vesubian live slope lattice planned in Action 4.

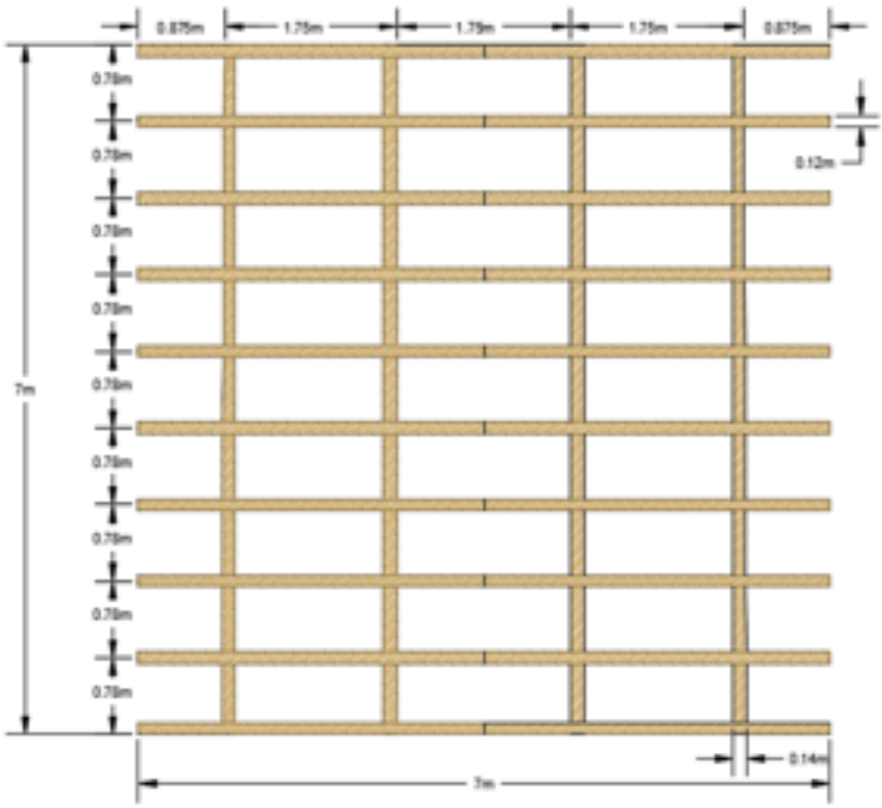


Figure 23. Plan view for the Vesubian live slope lattice planned in Action 4.

Table 9. Plant species and individuals envisaged for the Vesubian live slope lattice planned in Action 4.

	1st level	2nd level	3rd level	4th level	5th level	6th level	7th level	8th level	9th level	Units/individuals
Hawthorn (*Crataegus monogyna)*		9	9	9	9					36
Boom (*Cytisus scoparius L.*)						6	6	9	9	30
Gorse (*Ulex europaeus L.)*						9	9	6	6	30
Sycamore (*Acer pseudoplatanus L.*)	10	9	9	9	9	3	3	3	3	58
Basket willow (*Salix viminalis L.)*	4									4
Silver birch (*Betula pendula Roth*)	4									4
Units/individuals	18	18	18	18	18	18	18	18	18	162

Table 10. Characteristics of Action 4.

Description	**Dimensions**
Two levels wooden vegetated palisade	9 m
One level wooden vegetated palisade	18 m
Vesubian live slope grid (7x7m)	1 un
Plantation of vegetation in AF (Slope grid A)	162 un
Plantation of Hawthorn (Crataegus monogyna)	36 un
Plantation of Broom (Cytisus scoparius L.)	30 un
Plantation of Gorse (Ulex europaeus L.)	30 un
Plantation of Basket willow (Salix viminalis L.)	58 un
Plantation of Sycamore (Acer pseudoplatanus)	4 un
Plantation of Birch (Betula pendula Roth)	4 un

7.5. Action 5: Brush layer

Action 5 (Fig. 5) comprises a brush layer with 8 steps (Figs 22). This action has been designed for an active slope zone showing visible shallow landslide signs (Fig. 21). However, the soil depth in this section is uncertain and re-design or action alternatives may be devised in case the soil depth is not beyond 0.75 m in this section. A description of brush layer is provided in Section 6.1. However, the dimensions of Action 5 (Fig. 22) require the utilisation of high quantities of plant materials for the correct stabilisation of the intervened section in the long run. It is worth noting that brush layers are particularly effective on zones with deep soils and moderately wet.

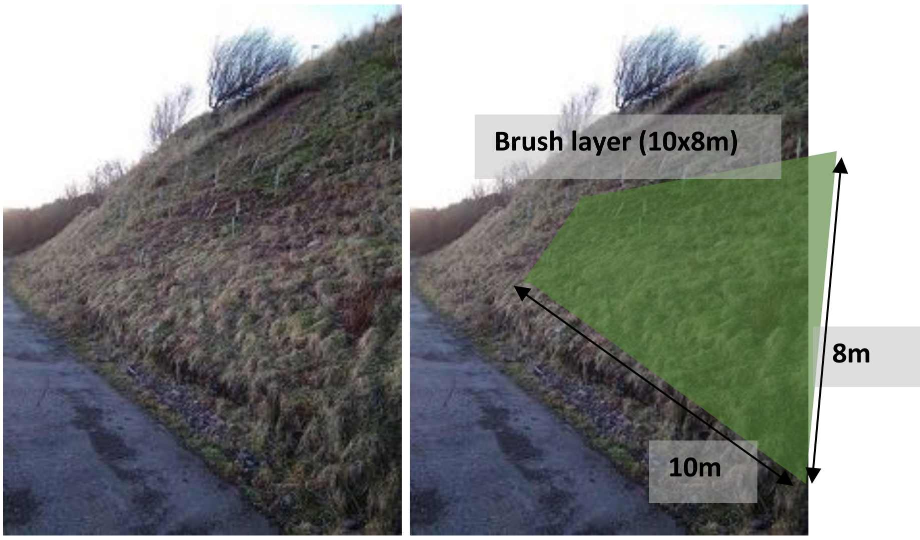


Figure 24. Location and layout of Action 5.

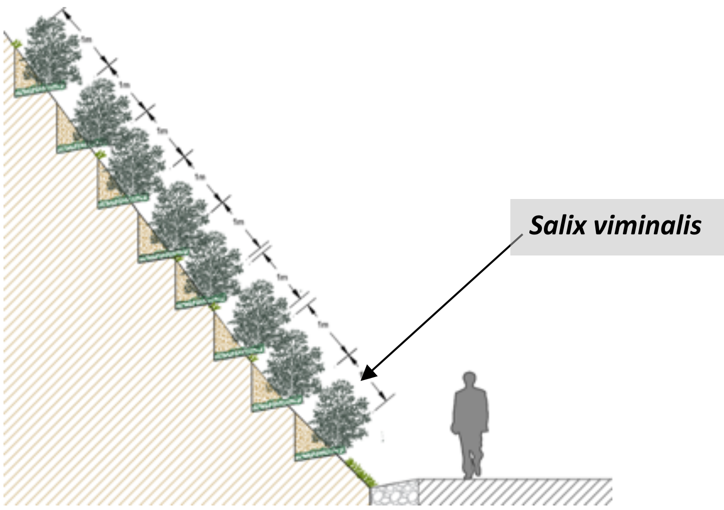


Figure 25. Profile view for the brush layers planned in Action 5.

Table 11. Characteristics of Action 5.

Description	Dimensions
Brush layer	80 m^2

7.6. Action 6: Three-dimensional blanket and live earth anchors

Action 6 (Fig. 5) comprises the deployment of earth anchors in combination with seeded bags and an organic, erosion control blanket. This action has been designed for an active slope zone showing visible landslide signs (Fig 23), but without apparent soil saturation signs. The soil depth in this slope section is shallow, so the deployment of this NBS will re-establish the topsoil and enable the development of a vegetation cover.

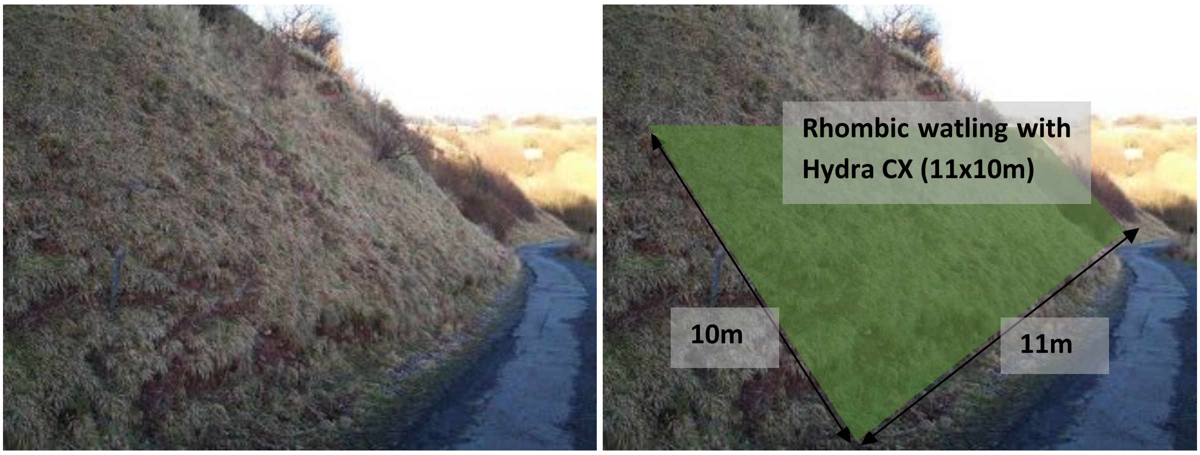


Figure 26. Location and layout of Action 6.

Table 12. Characteristics of Action 6.

Description	Dimensions
Three-dimensional blanket and live earth anchors	110 m^2

7.7. Action 7: Live Krainer-Cribwall and internal live palisade

Action 7 (Fig. 5) intends to transform the slope profile into a more stable profile by reducing the slope gradient of the zone for which the action is designed. To do so, Action 7 comprises the deployment of two different techniques -i.e. live Krainer cribwall deployed at the slope's toe and a live palisade deployed above the cribwall. A live Krainer cribwall is a wooden frame or structure built by deploying two to three levels of timber logs orthogonally. A live Krainer cribwall presents two levels of timber logs deployed horizontally and against the slope gradient -i.e. internal and external level (Fig. 24); the simple live cribwall only has one external level of horizontally deployed timber logs). Once the timber structure is built, this is backfilled with earth and plant materials. Like the other proposed actions, the objective is to stabilise the structure and the slope through the establishment of a vegetation cover, which, in the long term, will provide mechanical and hydrological reinforcement to the structure.

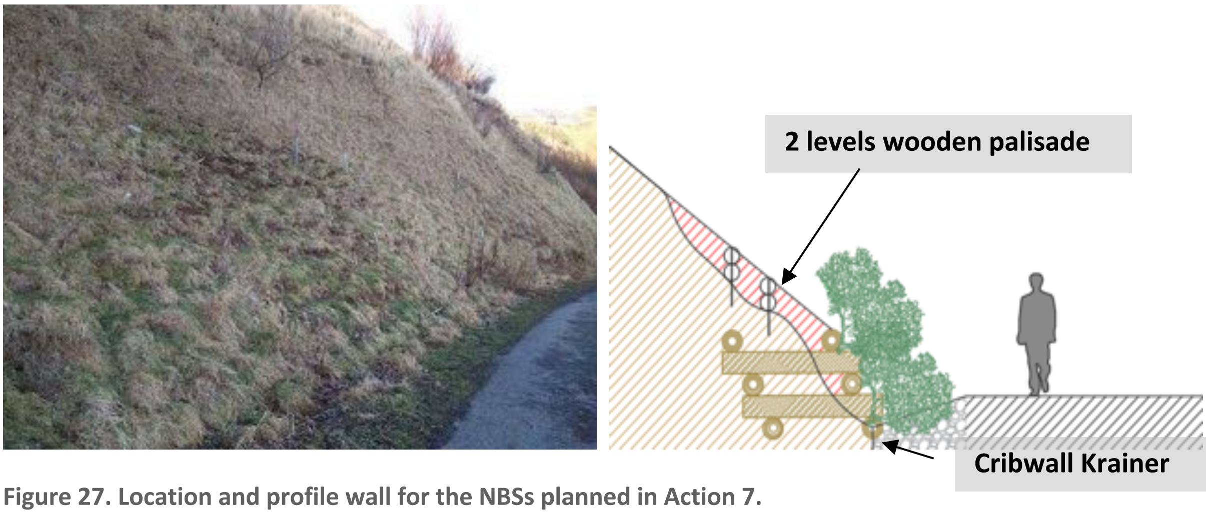


Figure 27. Location and profile wall for the NBSs planned in Action 7.

Table 13. Plant species and individuals distribution envisaged for the Krainer cribwall planned in Action 7.

	1st level	2nd level	3rd level	Units/individuals
Hawthorn (*Crataegus monogyna*)		5		5
Boom (*Cytisus scoparius L.)*			15	15
Gorse (*Ulex europaeus L.)*		5	5	10
Basket willow (*Salix viminalis L.*)	15	15	5	35
Sycamore (*Acer pseudoplatanus L.*)	5			5
Silver birch (*Betula pendula Roth*)	5			5
Units/individuals	25	25	25	75

Table 14. Characteristics of Action 7.

Description	**Dimensions**
Cribwall Krainer (1.6m tall)	10 m
2 levels internal wooden palisade	20 m
Plantation of vegetation in AF	75 un
Plantation of Hawthorn (Crataegus monogyna)	5 un
Plantation of Broom (Cytisus scoparius L.)	15 un
Plantation of Gorse (Ulex europaeus L.)	10 un
Plantation of Basket willow (Salix viminalis L.)	35 un
Plantation of Sycamore (Acer pseudoplatanus)	5 un
Plantation of Birch (Betula pendula Roth)	5 un

7.8. Action 8: Live palisade + live cribwall + slope lattice

The zone for which Action 8 (Fig. 5) has been designed presents serious soil consolidation problems (Fig 25). As a result, a new slope profile will be created to reduce the slope gradient, improve soil consolidation and strength and thus reduce the likelihood of landslides and surface erosion events. To create a new slope profile, Action 8 comprises the implementation of three different techniques that will be deployed in combination (Fig. 26) – i.e. (i) two-level live palisade at the slope's toe; (ii) simple live cribwall: middle slope section; and (iii) slope lattice: at the top slope section. These techniques have been described before (see Actions 2, 3, and 4 in Sections 6.2, 6.3, and 6.4, respectively).

Figure 28. Location of Action 8.

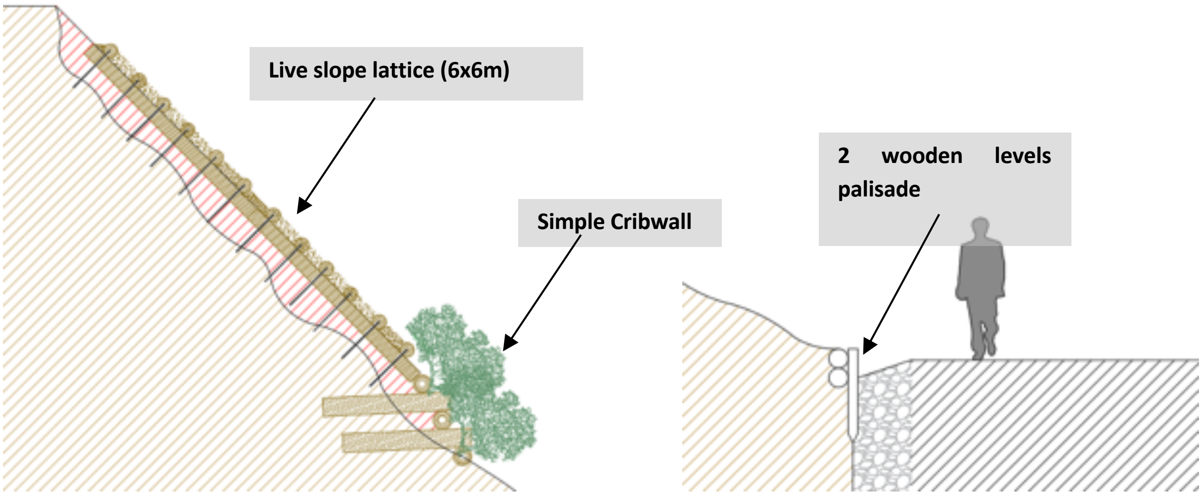


Figure 29. Profile view for the live slope lattice, cribwall, and palisade planned in Action 8.

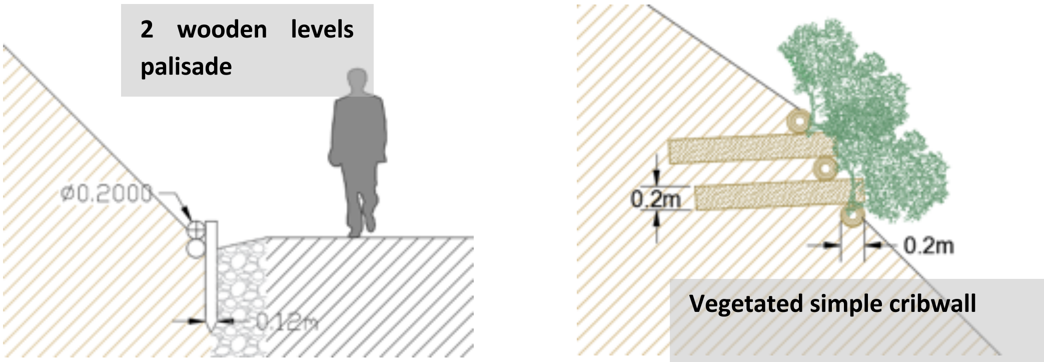


Figure 30. Profile view for the palisade and simple cribwall planned in Action 8.

Table 15. Plant species and individuals distribution envisaged for the simple cribwall planned in Action 8.

	1st level	2nd level	3rd level	Units/individuals
Hawthorn (*Crataegus monogyna*)		10		10
Boom (*Cytisus scoparius L.)*			10	10
Gorse (*Ulex europaeus L.)*		5	5	10
Basket willow (*Salix viminalis L.*)	20	5	5	30
Units/individuals	20	20	20	60

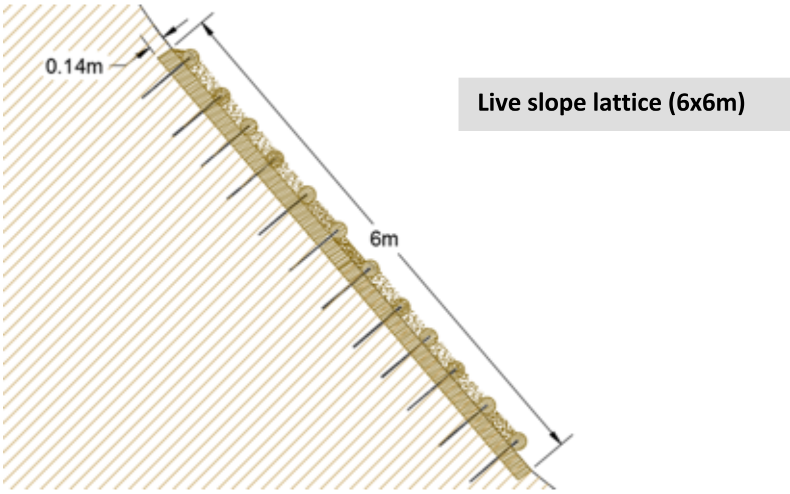


Figure 31. Profile view for the live lattice planned in Action 8.

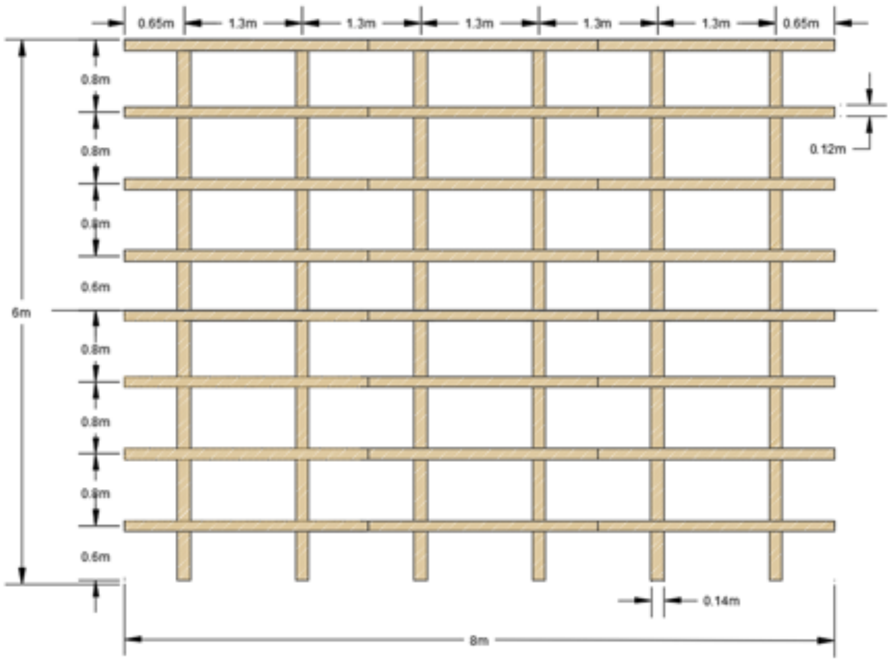


Figure 32. Plan view for the live lattice planned in Action 8.

Table 16. Plant species and individuals distribution envisaged for the live lattice planned in Action 8.

	1st level	2nd level	3rd level	4th level	5th level	6th level	7th level	8th level	Units/individuals
Hawthorn (*Crataegus monogyna)*		8	8	8					24
Boom (*Cytisus scoparius L.*)					4	4	8	8	24
Gorse (*Ulex europaeus L.)*					8	8	4	4	24
Basket willow (*Salix viminalis L.)*	16	8	8	8	4	4	4	4	56
Units/individuals	16	16	16	16	16	16	16	16	128

Table 17. Characteristics of Action 8.

Description	**Dimensions**
2 levels wooden palisade	15 m
Vegetated simple cribwall of 1,2 m high	8 m
Live slope grid (6x6m)	1 un
Plantation of vegetation in AF (Live simple cribwall)	60 un
Plantation of Hawthorn (Crataegus monogyna)	10 un
Plantation of Broom (Cytisus scoparius L.)	10 un

Plantation of Gorse (Ulex europaeus L.)	10 un
Plantation of Basket willow (Salix viminalis L.)	30 un
Plantation of vegetation in AF (Live slope grid)	128 un
Plantation of Hawthorn (Crataegus monogyna)	24 un
Plantation of Broom (Cytisus scoparius L.)	24 un
Plantation of Gorse (Ulex europaeus L.)	24 un
Plantation of Basket willow (Salix viminalis L.)	56 un

7.9. Action 9: Brush layer (medium scale).

Action 9 (fig. 5) has been designed for a slope zone in which the gradient is high and with evident landslide and surface erosion signs at the toe (Fig. 30). The soil depth and wetness observed in the zone for which Action 9 has been designed suggests that the implementation of a brush layer could be a successful intervention against shallow landslides and erosion.

Figure 33. Location and layout of Action 9.

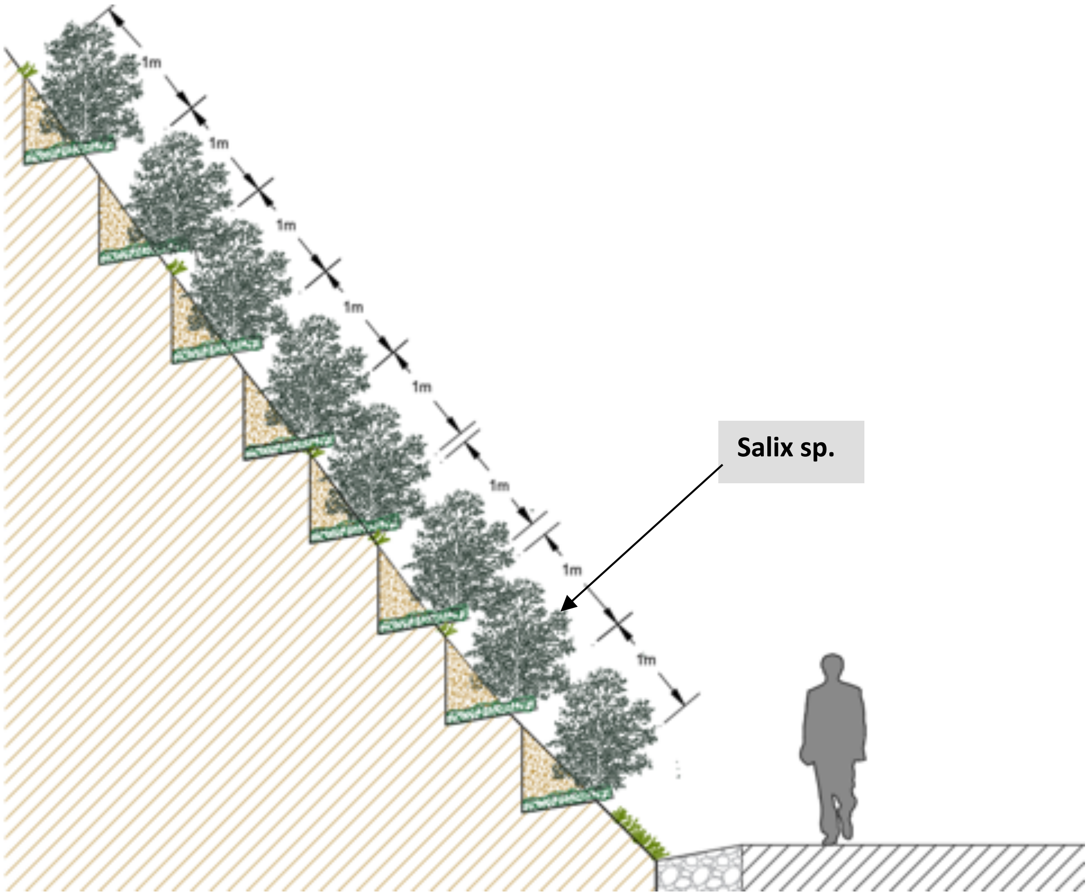


Figure 34. Profile view for the brush layer planned in Action 9.

Table 18. Characteristics of Action 9.

Description	Dimensions
Brush layer (8x10m)	80 m^2

7.10. Action 10: Vertical wall stabilisation with a "Loricata" cribwall

Action 10 (Fig. 5) has been designed for a zone with evident signs of slope failure and in which a vertical profile wall has been cut at the slope's toe to protect a heritage building. (Fig. 32) A "loricate" cribwall has been designed for this zone (Fig. 33). This NBS comprises a stainless steel frame or stand anchored to the ground and on which timber logs are deployed horizontally. The space between the NBS structure and the wall is backfilled with compacted earth materials that are then re-vegetated with plant cuttings, seeds, and bundles.

Figure 35. Location and layout of Action 10.

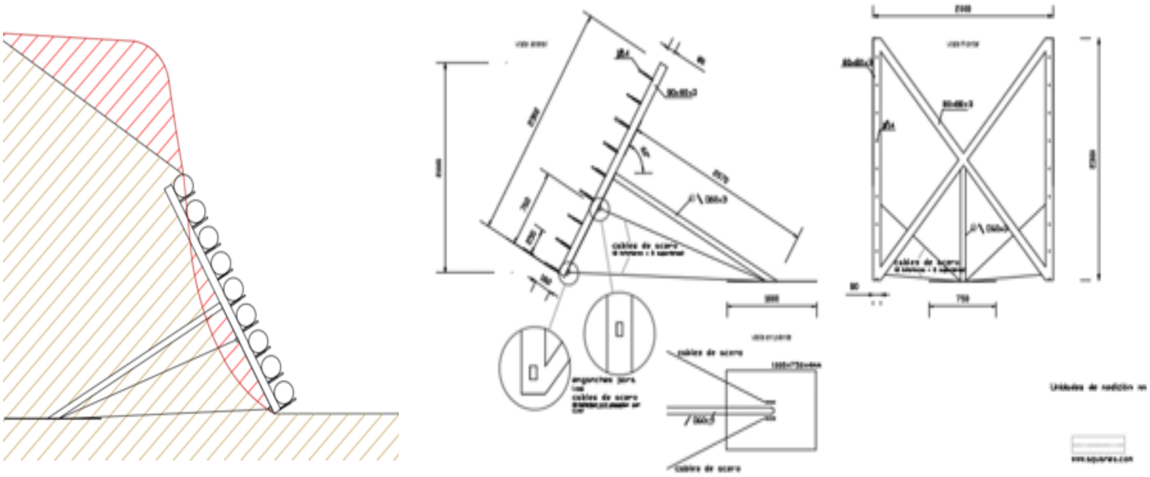


Figure 36. Profile view and design features for the Loricata Cribwall planned in Action 10.

Table 19. Plant species and individuals distribution envisaged for the Loricata Cribwall planned in Action 10.

	1st level	2nd level	3rd level	4th level	5th level	6th level	7th level	8th level	9th level	Units/individuals
Hawthorn (*Crataegus monogyna)*		10	15	15	15					55
Boom (*Cytisus scoparius L.*)						10	10	15	15	50
Gorse (*Ulex europaeus L.)*						15	15	10	10	50
Basket willow (*Salix viminalis L.)*	20	20	15	15	15	5	5	5	5	105
Sycamore (*Acer pseudoplatanus L.*)	5									5
Silver birch (*Betula pendula Roth*)	5									5
Units/individuals	30	30	30	30	30	30	30	30	30	270

Table 20. Characteristics of Action 10.

Description	Measurements
Loricata cribwall (2m tall)	12m (4 Loricata)
Plantation of vegetation in AF	270 un
Plantation of Hawthorn (Crataegus monogyna)	55 un
Plantation of Broom (Cytisus scoparius L.)	50 un
Plantation of Gorse (Ulex europaeus L.)	50 un
Plantation of Basket willow (Salix viminalis L.)	105 un
Plantation of Sycamore (Acer pseudoplatanus)	5 un
Plantation of Birch (Betula pendula Roth)	5 un

7.11. Action 11: Scenic footpath stabilisation with slope lattice

Action 11 (Fig. 5) is proposed to stabilise a scenic footpath showing evident signs of instability and surface erosion due to the slope gradient present underneath the path (Fig. 34). A slope lattice (Fig. 35) will provide a robust wooden skin to the slope below the path, reducing the tension of the slope and creating stable conditions for the establishment of a dense vegetation cover.

Figure 37. Location and layout of Action 11.

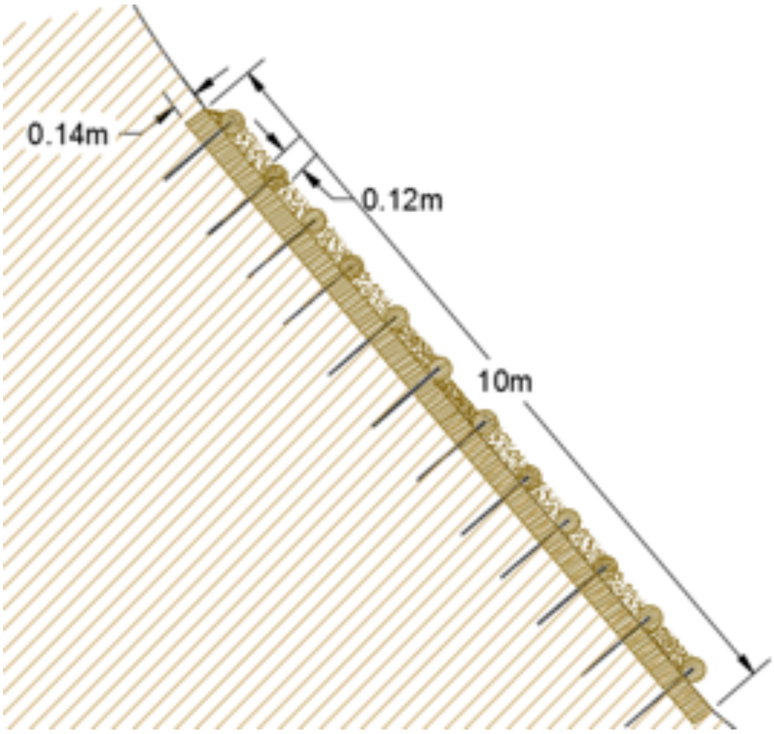


Figure 38. Profile view for the live lattice planned in Action 11.

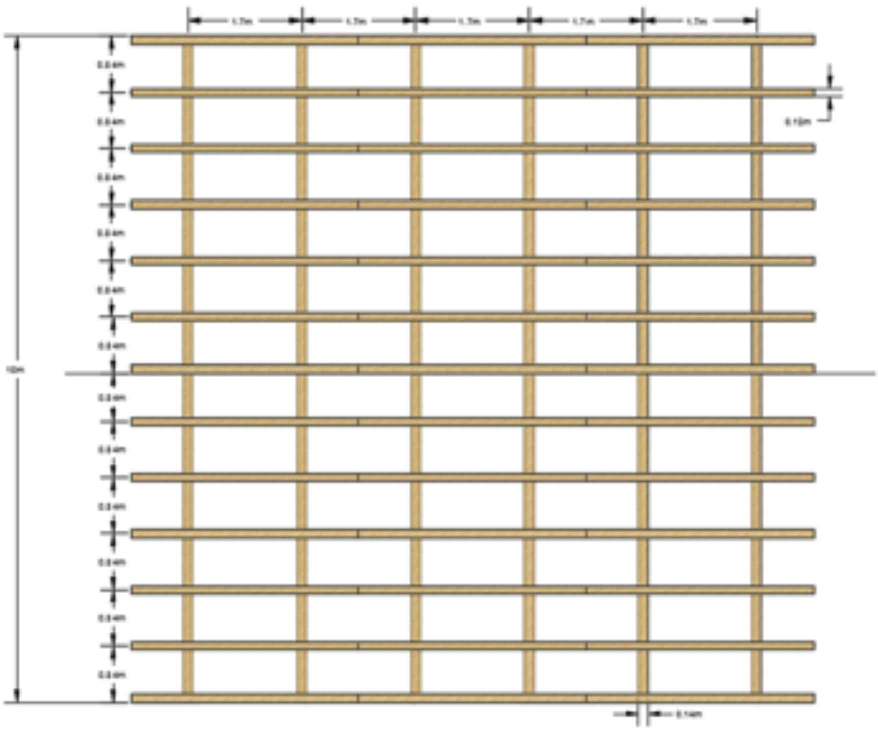


Figure 39. Plan view for the live lattice planned in Action 11.

Table 21. Plant species and individuals distribution envisaged for the live lattice planned in Action 11.

	1st level	2nd level	3rd level	4th level	5th level	6th level	7th level	8th level	Units/individuals
Hawthorn (*Crataegus monogyna)*	5	5	15	15					40
Boom (*Cytisus scoparius L.*)					5	5	15	15	40
Gorse (*Ulex europaeus L.)*					15	15	5	5	40
Basket willow (*Salix viminalis L.)*	20	20	10	10	5	5	5	5	80
Units/individuals	25	25	25	25	25	25	25	25	200

Table 22. Characteristics of Action 11.

Description	**Dimensions**
Live slope grid (10x10m)	1 un
Plantation of vegetation in AF	200 un
Plantation of Hawthorn (Crataegus monogyna)	40 un

Plantation of Broom (Cytisus scoparius L.)	40 un
Plantation of Gorse (Ulex europaeus L.)	40 un
Plantation of Basket willow (Salix viminalis L.)	80 un

8. Management of the planned NBSs

Most of the planned NBS techniques do not present any management requirements. However, some management actions will ensure the adequate development, functioning and services provision of the planned NBSs. The following maintenance actions are envisaged for the planned interventions:

- Pruning trees and shrubs every two years. It is not required to prune all the vegetation cover at the same time, and the retrieved plant materials can be used for further interventions. Usually, one cutting is implemented after the second and the fourth year, after which the NBS is left unmanaged.
- Selective removal of weeds, invasive plant species and woody plant branches to reduce plant competition and enable light to reach zones where plant development should be adequate to achieve an optimum performance of the NBS.
- Fertilisation – in cases where the soil properties are poor, it may be convenient to use organic amendments to foster vegetation growth within the NBS.
- Control of negative impacts from cattle and rabbits. If the pressure is high, it is advisable to protect the intervention with a fence for at least two years.
- Be aware of any modifications of the intervention area. For example, impermeabilisation of new areas and generated stormwater, or new infrastructures that can affect directly or indirectly to the performance of the planned NBS.

9. Monitoring the performance and ecosystem services provision of the planned NBS actions at OAL-UK

The conceptual model shown below (Fig. 37) illustrates the approach for selecting indicators for monitoring the establishment and performance of Nature-based Solutions (NbS) against hydro-meteorological hazards at OAL-UK. The simplified approach described herein is compatible with the proposed in OPERANDUM's Deliverable 3.4 of WP3 as well as transferable and reproducible between OALs. Three indicators' selection criteria are set: (i) context, (ii) performance, and (iii) provision. These criteria are distributed across two hierarchical levels. The top hierarchical level is context-dependent, and it influences decisions on the actions or NbS that can be established at a given hazard-prone site. At this level, factors related to the scale, environmental and socio-economic attributes are considered relevant to define site-specific NbS. The lower hierarchical level strives to evaluate the performance of NbS deployed at a given hazard-prone site. Performance is herein divided into eco-engineering performance and socio-ecological performance. The former considers quantitative and measurable variables related to the functioning, stability, resilience, and evolution of the NbS created or restored through the deployment of a given NbS following engineering standards. These variables are related to physical, geographical, chemical, hydrological, biological, engineering and any combination of the above factors. The latter group considers both quantitative and qualitative variables related to the provision of ecosystem services to human communities. A comprehensive but not definitive list of indicators is provided in the supplementary document to this conceptual model (Table 22). The same indicators listed in Table 2 have been reported in Deliverable 3.4 of WP3. These indicators are meet the criteria of credibility, salience, legitimacy and feasibility established in WP3

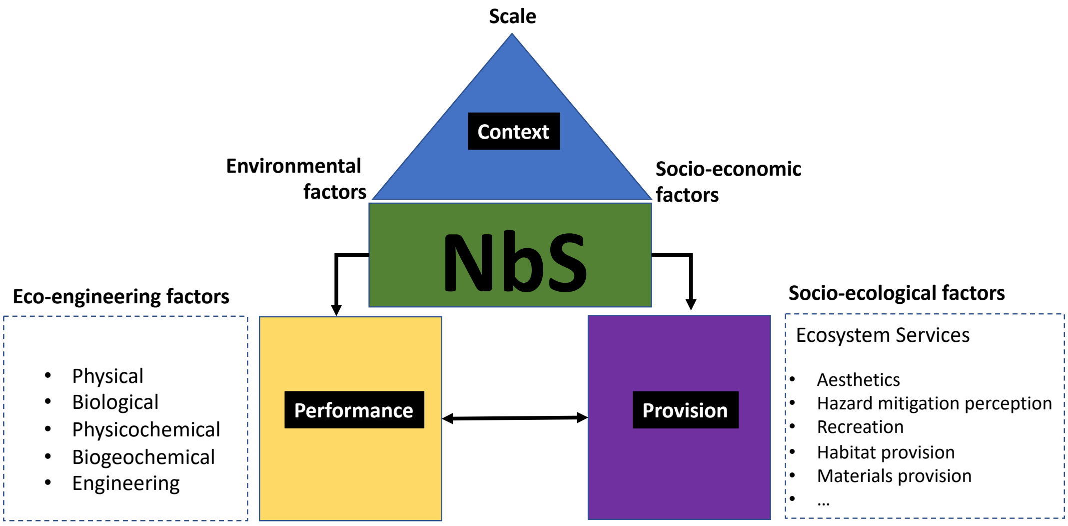


Figure 40. Conceptual model for selecting indicators to monitor the establishment and performance of NBS at the OAL level.

Table 23. Proposed indicators to monitor the performance of the proposed NBS at OAL-UK.

Category	Indicator	Type	Data collection	Spatial pattern
Societal impact	Socio-economic profile	Socio-economic	statistical data	
Geophysical properties	Climate classification	Physical	statistical data	point
Geophysical properties	Land cover	Socio-economic	Earth observation	polygon
Soil conditions	Soil type	Physical	direct measurement/machine learning	distributed
Geophysical properties	Topography	Physical	Earth observation	distributed
Geophysical properties	Landscape capacity	Socio-ecological	direct measurement	distributed
Soil conditions	Soil matric suction	Physical	direct measurement	point
Soil conditions	Soil moisture	Physical	direct measurement	point

Soil conditions	Soil water retention	Physical	direct measurement	point
Soil conditions	Soil temeperature	Physical	direct measurement	point
Hydrological	Water table height	physical	direct measurement	point
Soil conditions	Soil organic matter	Physicochemical	direct measurement	point
Soil conditions	Soil nutrients	Chemical	direct measurement	point
Soil conditions	Soil strength	Physical	direct measurement	point
Soil conditions	Soil respiration	Biochemical	direct measurement	point
Ecological impact	Plant growth	Biological	direct measurement	point
Ecological impact	Plant biomass	Biological	indirect measurement	point
Ecological impact	Plant cover	Biological	direct measurement	distributed
Ecological impact	Plant diversity	Biological	direct measurement	distributed
Ecological impact	Plant mortality	Biological	direct measurement	distributed
Hydrological	Rainfall interception	Physical	direct measurement	polygon
Hydrological	Stemflow	Physical	direct measurement	point
Ecological impact	Root profile	Biological	indirect measurement	distributed
Soil conditions	Root pull-out force	Physical	direct measurement	point
Ecological impact	Soil fauna	Biological	direct measurement	polygon
Ecological impact	Wood decay	Physical	direct measurement	polygon
Soil conditions	Solid materials transport	Physical	direct/indirect measurement	distributed
Hydrological	Runoff	Physical	direct/indirect measurement	distributed
Soil conditions	Soil mass movement	Physical	direct measurement / remote sensing	distributed

Hydrological	stream flow attenuation	Physical	direct measurement	polyline
Hydrological	channel width	Physical	direct measurement	polyline
Hydrological	sedimentation	Physical	direct measurement	polygon
Ecological impact	Shellfish counts	Biological	direct measurement / modelling	polygon
Ecological impact	Shellfish diversity	Biological	direct measurement / modelling	polygon
Geophysical properties	beach erosion	Physical	Earth observation	distributed
Hydrological	wave attenuation	physical	direct measurement / calculations	polyline
NBS structure	Resistance against sliding	Physical	direct measurement / calculations	point
NBS structure	Resistance against overturning	Physical	direct measurement / calculations	point
NBS structure	Resistance to shear failure	Physical	direct measurement / calculations	point
NBS structure	Resistance to bending/compression/tension	Physical	direct measurement / calculations	point
NBS structure	Resilience of the NBS structure	Physical	indirect measurement	point
NBS structure	Durability of the NBS strucutre	Physical	direct measurement / indirect measurement	point
NBS structure	Constructability of NBS structure	Physical	indirect measurement	point
Economic impact	Energy use	Socio-economic	indirect measurement	point
Economic impact	Water consumption	Socio-economic	direct measurement / calculations	point
Economic impact	Waste reduction	Socio-economic	direct measurement / indirect measurement	point
Societal impact	Noise / vibration	Physical	direct measurement	point
Economic impact	Wholelife cost	Socio-economic	direct measurement / calculations	point
Economic impact	Operational cost	Socio-economic	direct measurement	point

Societal impact	Access	Socio-ecological	survey	polygon
Societal impact	Aesthetic perception	Socio-ecological	survey	polygon
Societal impact	Risk mitigation perception	Socio-ecological	survey	polygon
Economic impact	Materials provision	Socio-ecological	survey	polygon
Societal impact	Recreation	Socio-ecological	survey	polygon
Economic impact	Employment generation	Socio-ecological	survey	polygon
Economic impact	Tourism generation	Socio-ecological	survey	polygon
Societal impact	Cultural heritage	Socio-ecological	survey	polygon
Ecological impact	water cycle regulation	Socio-ecological	indirect measurement	polygon
Ecological impact	carbon cycle regulation	Socio-ecological	indirect measurement	polygon
Ecological impact	air quality regulation	Socio-ecological	indirect measurement	polygon
Ecological impact	climate regulation	Socio-ecological	indirect measurement	polygon
Ecological impact	habitat provision	Socio-ecological	indirect measurement	polygon
Ecological impact	habitat support	Socio-ecological	indirect measurement	polygon
NBS structure	quality of construction	Socio-ecological	indirect measurement	polygon
Ecological impact	landscape quality	Socio-ecological	survey	polygon
Societal impact	Socio-economic profile	Socio-economic	statistical data	

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