Use of Trees and Vegetation to Stabilise Cliffs and Shallow Landslides

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Dorset Future Coast

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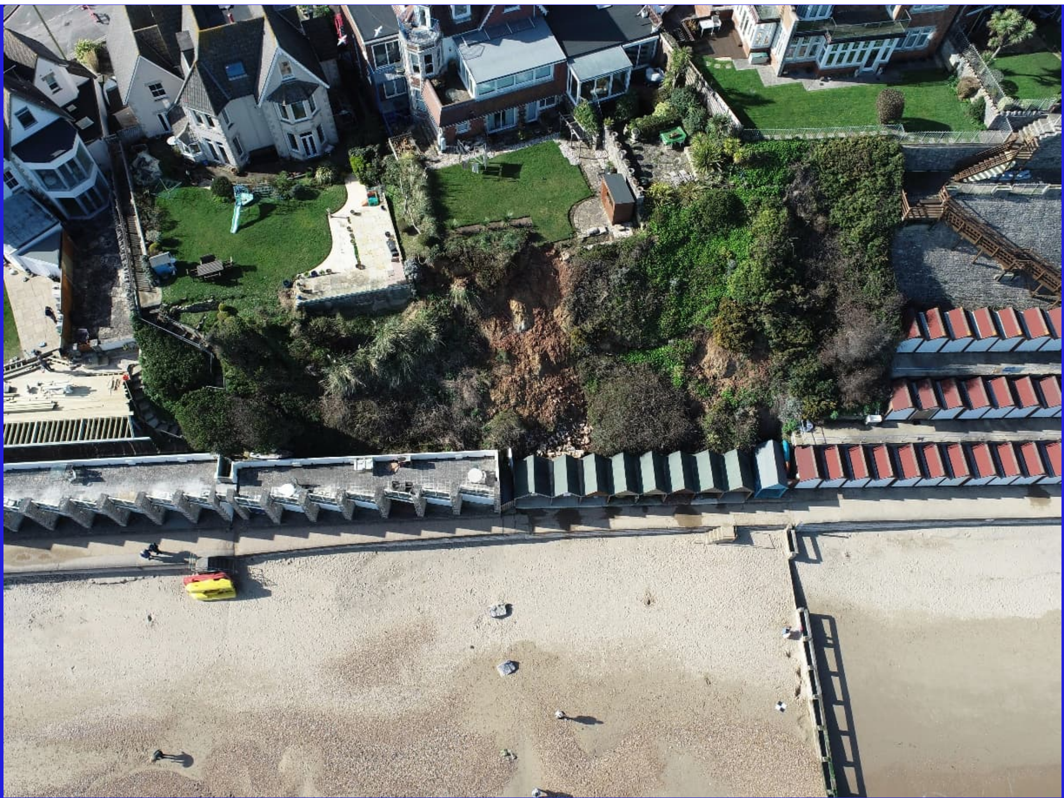

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Jacobs U.K. Limited

Cottons Centre
Cottons Lane
London SE1 2QG
United Kingdom

T +44 (0)203 980 2000
www.jacobs.com

Executive summary

Use of trees and vegetation as a primary measure to improve the stability of cliffs and landslides is a little used method yet has potential benefits as a cost effective nature-based solution. Trees and vegetation are, however, widely used for bioengineering and landscaping for slope engineering and landslide stabilisation projects, and the benefits are well known. Reasons why the option has rarely been used alone for natural cliffs are likely to include the relative inaccessibility and safety of coastal cliffs, uncertain benefits and success of planting schemes over the natural colonisation and regeneration of coastal cliffs, the requirement for specialists in engineering geomorphology, ecology and arboriculture involvement in the investigation, design and evaluation of schemes, and inexperience of suppliers and contractors.

Sections 1 and 2 of this report set out the principles, benefits and influences of trees and vegetation on the stability of coastal cliffs and landslides.

Section 3 assesses the suitability of potential tree and vegetation planting sites at North Cliffs, Swanage, and Charmouth, Dorset, based on detailed knowledge of the cliff geomorphology and ground behaviour mapping carried out for Dorset Future Coast. Zonation maps for both sites are included in Appendix A.

Section 4 provides a listing of tree and ground cover plant species suitable for coastal cliff environments on the south coast of England, including Swanage and Charmouth.

Section 5 provides high-level guidance for the requirements and safe design of schemes. Outline consideration of the range of safe access and installation methods is provided, along with some thoughts on obtaining tree and plant stock, and post-installation monitoring and maintenance. Other general guidance is provided on tree and vegetation management for developers and landowners and use of tree preservation orders if required.

Contents

Appendices

Tables

Figures

1. Introduction

The hydrological and mechanical effects of vegetation on slope stability—both beneficial and adverse—are well documented in the literature. Foundational works such as Coppin and Richards (1990), Morgan and Rickson (1995), and Gray and Sotir (1996) laid the groundwork, while more recent studies have refined our understanding. DiBiagio et al. (2024) provide a comprehensive review of vegetation parametrisation in slope stability models, and Gong et al. (2024) explore the role of herbaceous species in enhancing slope resilience.

Despite these advances, quantifying the net hydrological impact and root-reinforced soil strength with depth remains challenging. Liu (2021) and Al Mahamid & Alskaf (2024) highlight ongoing uncertainties in modelling root-soil interactions, particularly under dynamic moisture conditions. These limitations have historically hindered the widespread adoption of bioengineering as a primary slope stabilisation method.

However, the integration of slope bioengineering and ecological landscaping has gained significant traction, especially in Southeast Asia (Howell 1999 and Martin 2001), where environmental sustainability is increasingly prioritised in infrastructure development. Wan Mohamed et al. (2022) document successful applications of native vegetation for erosion control and shallow failure mitigation in tropical climates. In the UK, cliff vegetation schemes have generally been combined with other solutions such as drainage, soil reinforcement, slope reprofiling, soil nailing and other structural measures (walls) e.g. Ground Engineering (2001); examples include Filey Bay, North Yorkshire, Canford Cliffs, Dorset, and Belton Way, Southend-on-Sea, Essex.

Before delving into the complex interactions between vegetation and slope stability, it is essential to revisit fundamental soil mechanics principles to contextualize these biological influences.

1.1 Soil Mechanics Principles

Landslides occur when the gravitational driving forces acting downslope exceed the resisting forces provided by the slope materials. A slope is considered stable when the resisting forces—primarily shear strength—are greater than the destabilising forces, resulting in a margin of stability. Conversely, a slope at the point of failure has no margin of stability, where resisting and driving forces are approximately equal.

This balance is quantified using the Factor of Safety (FoS), defined as:

$$\text{Factor of Safety} = \frac{\text{Resisting forces}}{\text{Destabilising forces}} = \frac{\text{Shear strength}}{\text{Shear stress}}$$

A slope at the critical point of failure has a Factor of Safety equal to 1.0.

Shear strength represents the maximum shear stress a material can withstand before failure. The portion of shear strength actively resisting destabilising forces is termed mobilised shear strength, which is typically less than the total available shear strength. At failure, shear strength is fully mobilised along a defined failure surface.

In 1776, Coulomb formulated a relationship for shear strength (S) as:

$S = c + \sigma \tan\phi$

Where:

c = cohesion (independent of normal stress)

σ = normal stress acting perpendicular to the failure plane

ϕ = angle of internal friction

This equation illustrates that frictional resistance increases with normal stress, while cohesion remains constant.

However, porewater pressure plays a critical role in slope stability. Water reduces particle-to-particle contact, thereby diminishing the frictional component of shear strength. The effective stress (σ') - the portion of normal stress contributing to shear resistance - is defined as:

$\sigma' = \sigma - u$

Where:

u = porewater pressure.

The modified Coulomb equation incorporating effective stress becomes:

$S = c' + (\sigma - u) \tan \phi'$

Where:

c' = effective cohesion

ϕ' = effective angle of internal friction

This formulation is fundamental in geotechnical engineering and underpins slope stability analysis, particularly in saturated or partially saturated soils.

2. Vegetation and Slope Stability

Vegetation can influence cliff/slope stability, both positively (reducing shear stress or increasing shear strength) and negatively (increasing shear stress or decreasing shear strength) in a number of ways:

- +ve by extraction of soil moisture and reducing the soil moisture balance
- +ve by lowering groundwater levels and reducing pore water pressures on existing or potential landslide shear surfaces
- +ve by binding/reinforcing soil strength and root anchoring of landslide shear surfaces
- -ve by loosening rock blocks (wedging and wind throw), increasing the potential for rock / boulder falls, and
- -ve by loading (adding weight), increasing the destabilising force acting on slopes

These issues are discussed in turn in the following sections.

2.1 The Influence on Soil Moisture and Groundwater

Figures 1a and 1b present a simple model to illustrate the potential fate of rainfall on a bare and vegetated slope, respectively.

On bare slopes, only a proportion of the rainfall enters the soil (through *infiltration*) and recharges the groundwater table; the remainder either contributes to runoff (and enters stream channels or other drainage pathways) or is 'lost' through evaporation.

On vegetated slopes, an even lower proportion of rainfall contributes to groundwater recharge due to the effects of:

- *interception* by the tree canopy or other foliage, causing absorption or evaporation losses. The amount of interception losses is determined, in part, by the type and species of vegetation and the area of cover. Low ground cover provides less interception and evaporation than a tree cover, due to the lower surface roughness of the vegetation and resulting turbulent exchanges with the atmosphere.
- root extraction of soil moisture and groundwater and the subsequent loss to the atmosphere by *evapotranspiration*. Once again, vegetation type, species and ground cover are important factors in determining the rate of evapotranspiration. For example, it has been estimated that a deciduous forest can remove 1000kg of water/m^2 in a year, compared with 500kg/m^2 for a spruce forest (Schiechtl 1980).
- *root water uptake*: deep-rooted species can reduce pore water pressure along potential shear surfaces.

For deciduous trees, both interception and evapotranspiration losses are generally low during the winter months. As the winter months are characterised by periods of high groundwater levels and landslide activity, it follows that vegetation does not have a significant impact on most groundwater triggered landslide events. Where it can help is by delaying the recharge of the groundwater table within active shallow landslides (i.e. less than 3m deep being the depth of penetration of deep root systems) and thereby reduce the frequency of seasonal slope movements.

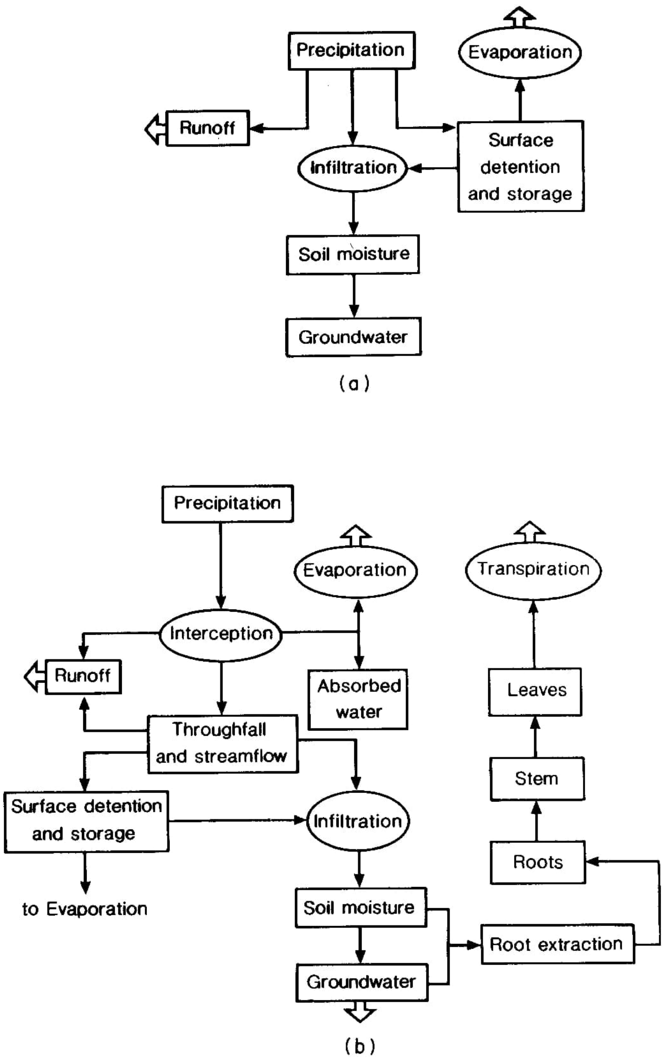


Figure 1. Hillslope hydrological cycles a) bare slope b) vegetated slope

In some circumstances, vegetation can actually have a detrimental effect on slope stability. For example, compared with bare soil, roots and stems may actually increase the ground surface roughness and soil permeability, leading to an increase in the infiltration rate (i.e. more rapid groundwater recharge). In addition, depletion of soil moisture by root extraction may lead to the formation of desiccation cracks during periods of dry weather, favouring more rapid infiltration. Although these cracks may close up during wet periods, soil permeability can be increased by up to 2 orders of magnitude (Anderson *et al.* 1982).

2.2 Soil Reinforcement and Anchoring

Soil reinforcement and anchoring of root systems can be viewed as increasing the shear strength of the slope materials by providing artificial cohesion (ΔC; this can be between 1 to 12kPa; Table 1) and increasing the frictional strength component (e_r). The Coulomb equation set out earlier can thus be re-written as follows:

$$S = (c' + \Delta C) + (\sigma - \lambda + e_r) \tan\phi'$$

This formulation is widely accepted in geotechnical engineering when accounting for **root reinforcement**. The term **ΔC** represents the additional cohesion provided by roots depending on vegetation type, root density, and soil conditions. The inclusion of $\mathbf{e_r}$ (frictional enhancement) is also valid, especially in granular soils where roots can interlock and increase resistance to shear.

Table 1. An indication of the strength contributed by roots

Plant	Soil	Increase in Apparent Cohesion (ΔC) (kPa)
Conifers (pine, fir)	Glacial till	0.9 – 4.4
Alder	Silt loam	2 – 12
Birch	Silt loam	1.5 – 9
Poplar	Silt loam	2 – 9
Alfalfa (lucerne)	Silty clay loam	4.9 – 9.8
Clover	Silty clay loam	0.1 – 2

Source: Selby 1982

Roots can have very high tensile strengths. For example, some tree roots can have tensile strengths of up to 90Mpa (i.e. 30% of the tensile strength of mild steel). The strength of grass roots is obviously much lower. Figure 2 provides an indication of the strength gain associated with roots of different vegetation types. The amount of reinforcement depends on the root area as well as their tensile strength.

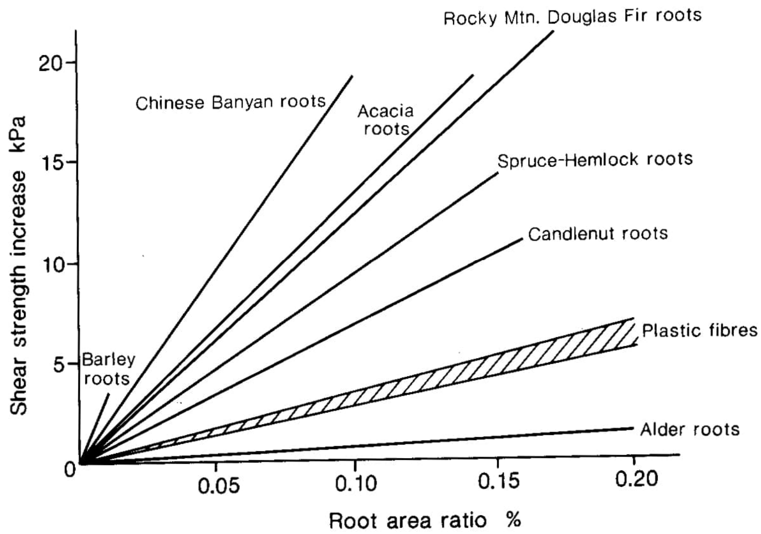


Figure 2. Comparison of the strength gain associated with different root fibre reinforcement (Source: Gray and Leiser 1982)

Taproots or sinker roots of many large trees can act as slope stabilising piles. The root cylinder anchors or buttresses the soil slope above and if the trees are close together arching may develop (Figure 3).

The significance of root reinforcement depends on the ground conditions and, hence, will vary significantly across an area of changeable rock and soil types. Figure 4 illustrates four settings where trees may influence the stability of slopes:

- *a relatively thin soil over a massive bedrock*. A plane of weakness may exist at the soil/bedrock surface. However, as the roots cannot penetrate the bedrock, they will not have a significant effect on preventing landsliding.
- *a relatively thin soil over a weathered bedrock.* As the bedrock contains many discontinuities (e.g. joints and bedding planes), roots will be able to penetrate and contribute significantly to slope stability. This situation can occur on relatively steep scarp faces behind individual landslide blocks.
- *thicker soils above weathered bedrock.* In many instances shear surfaces develop along the transitional layer between the soil and weathered bedrock. Roots penetrating this transitional layer will reinforce the soil and help prevent shallow landsliding or provide a degree of anchoring along an existing shear surface. This is a common situation in Swanage and Charmouth, where relatively steep scarp slopes and shallow landslides are present.
- *areas of existing or potential deep-seated landsliding*; in this case the landslide shear surfaces are well below the zone of influence of roots and, therefore, vegetation has little mechanical influence on landslides.

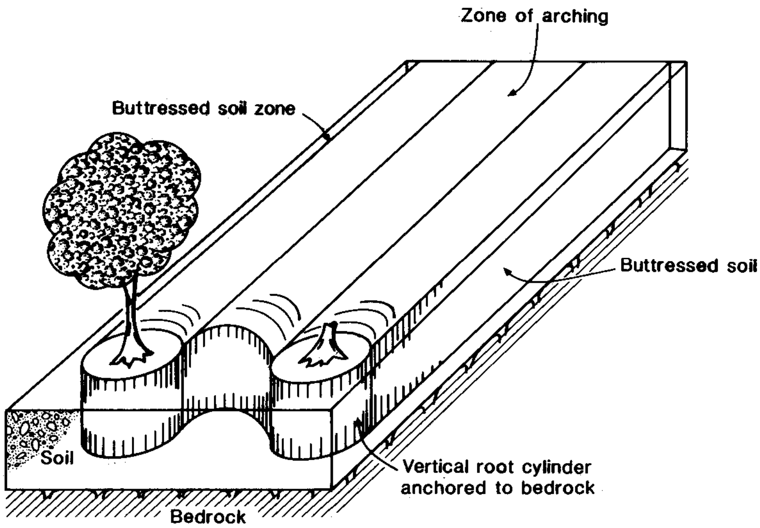


Figure 3. Root buttressing, anchoring and arching (Source: Greenway 1987)

2.3 Wedging of Blocks

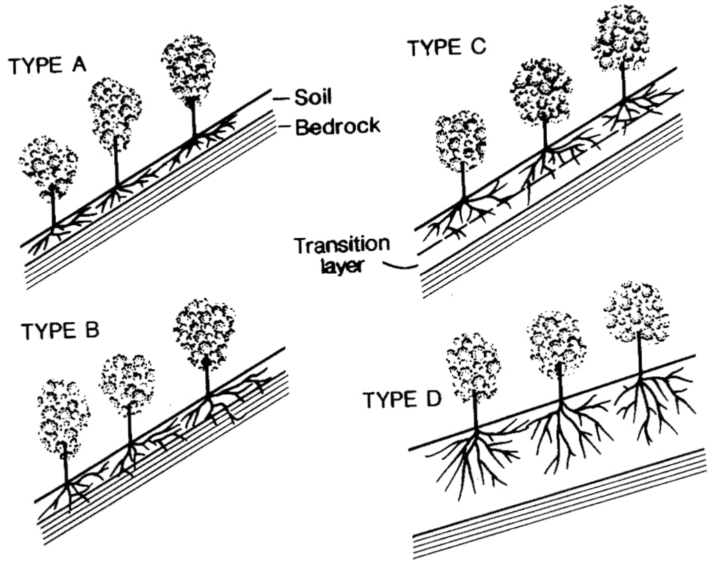
Root wedging can occur on exposed rock cliff faces. As roots grow into fractures and expand, they force discontinuities apart. This disrupts interblock cohesion and reduces the internal friction angle (ø′), which is critical for resisting shear failure in rock masses. It has been found that a 10cm diameter root, 1m in length can move a 41 tonne block (Birot 1962). Over time individual blocks can be dislodged and detached from the rock face. This process can destabilise cliff faces, especially where jointed or fractured rock is present.

Trees growing outward from slopes can act as levers, pivoting on the slope surface. This can exert additional mechanical stress on the slope, especially during high winds or when the tree mass increases. Levering can contribute to block detachment or shallow slope failures, particularly in marginally stable conditions.

The reduction in internal friction by wedging is often offset by root reinforcement, leaving the slope reliant on the additional root cohesion to maintain stability. In this condition even small surcharges such as that resulting from rainfall can trigger rockfalls. The combination of wedging and reinforcement can result in large rock falls as a dense root network can loosen significant amounts of debris before the root cohesion is broken.

While wedging reduces friction and promotes instability, root reinforcement (via cohesion and anchoring) can counteract this effect. The combination of wedging and reinforcement can loosen large volumes of debris, leading to massive rockfalls once the root network fails or is overwhelmed.

Given the above, planting of trees on rock cliff faces is not recommended. Where natural seeding of trees occurs it is recommended they are coppiced or removed before they mature to prevent root wedging and rock cliff failures.



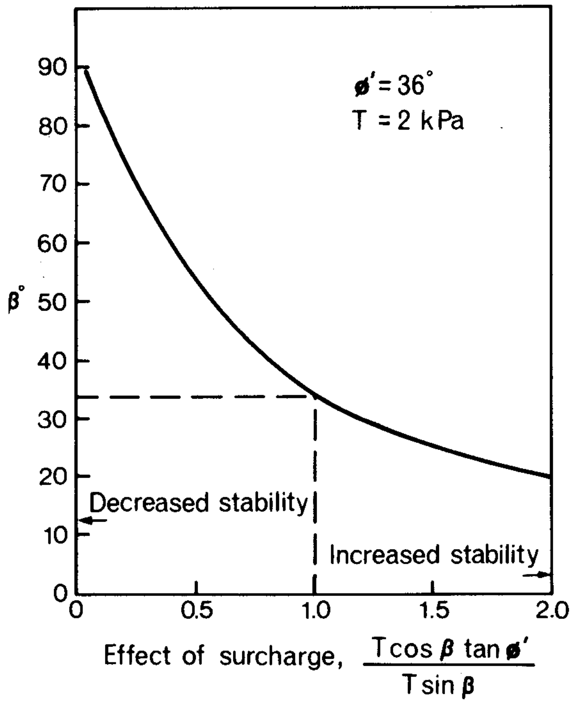
Type A: a relatively thin soil over a massive bedrock
Type B: a relatively thin soil over a weathered bedrock
Type C: thicker soils above weathered bedrock
Type D: areas of existing or potential deep-seated landsliding

Figure 4. Slope settings for root reinforcement and anchoring

2.4 Surcharge and Wind Shear Effects

Trees growing on unstable slopes can add additional weight (surcharge) on existing or potential failure surfaces. Estimates of the surcharge directly beneath individual trees range from 70kPa for a 60m-high Douglas fir trees to 5kPa for a 6m-high Sitka spruce. In most circumstances this surcharge will increase the normal stress (σ in the Coulomb equation) and, therefore, acts as a net stabilising influence. This is illustrated in Figure 5, for a soil with internal friction of 36° and a tree weight of 2kPa; trees increase stability on slopes up to 34°, thereafter leading to a net decline. However, the additional load from large trees close to cliff edges may contribute to localised slope instability problems.

Vegetation exposed to wind can transmit dynamic forces into a slope. The shear stress generated by wind is proportional to the wind velocity and the drag. Close to the edge of a wooded slope, wind speeds of 90km/hour can produce a transmitted shear stress of around 1kPa. This transmitted stress could, in theory, have an impact on slope stability. In reality, however, trees tend to blow over (windthrow) during high winds, as happened across southern England during the 1987 hurricane. If overturning occurs, then the infiltration rate may increase temporarily and lead to more rapid groundwater recharge (as described earlier).



Note: in the example shown, for slopes steeper than 34° for a given soil and tree cover, tree weight decreases stability

Figure 5. The effect of tree weight on slope stability (Source: Selby 1982)

3. Site Suitability for Trees and Vegetation Planting

A good understanding of the geomorphology of cliffs and slopes is required to identify suitable locations for cliff vegetation planting schemes. The geomorphology mapping and interpretation at Swanage and Charmouth provides an excellent framework to identify locations and suitable sites where vegetation planting is both feasible and stands the best chance of success.

Using Swanage as an example, the cliff morphology and mechanisms of instability at North Cliffs can be separated into four distinct groups:

1. Vertical cliffs formed of stronger sandstones subject to spalling of soil/rock, man-made artefacts and rockfalls
2. Steep cliffs formed of interbedded sandstones and mudrocks (locally forming benches) subject to local slumping and larger landslides due to coastal erosion and groundwater
3. Steep slopes formed of mudrocks subject to local seepage erosion and slumping
4. Talus slopes formed of debris beneath cliffs subject to slumping and landslides due to loading and groundwater

Table 2 summarises the typical cliff morphology features, constraints and potential benefits of tree and cover planting schemes.

For steep slopes and rock cliffs, vegetation may reinforce and loosen blocks. In many cases vegetation would probably have a net positive effect in reducing rockfalls, but this will not always be the case. Professional advice should be sought before removing vegetation from individual cliff faces and scarp slopes. It is noted that the removal of trees and vegetation from cliffs would need to be accompanied by removal of loose rocks or, in some circumstances, the provision of rock slope stabilisation measures such as netting or rock bolts. This is specialist work and should only be carried out by qualified rock slope stabilisation contractors.

For lithological and landslide benches, provided safe access is achievable and the slope and depth of the benches are relatively low (i.e. <15° and 3m deep), the combination of lowering of groundwater levels and root anchoring by trees and cover vegetation can have a significant stabilising effect. Natural decay or removal of deep-rooted vegetation in this context would increase the susceptibility of pre-existing landslide benches to higher rates of ground movement or landslide.

For landslides greater than 3m deep, the groundwater table and shear surfaces are likely to be too deep for tree root penetration to have a significant influence on stability. Further, the additional load of the trees may actually contribute to destabilisation of intermediate depth landslides.

Zonation maps of the suitability of trees and vegetation planting are provided in Appendix A.

Table 2. Morphology features, attributes and benefits of planting to improve cliff stability.

Morphological Feature	Attributes	Benefits
Cliff top edge & plateau	Generally accessible Soils / suitable Relatively low cost to implement	Low cover/shrub planting can bind soil and prevent ravelling of cliff edge Tall trees should be avoided to prevent wind-throw, wedging and destabilisation of edge
Steep cliff / vertical rock face	Difficult to access safely / adds to cost Rock outcrop / unsuitable Soft rock & soils / suitable Medium to high cost to implement	Low cover/shrub planting provides protection against wind and rain/spray and binds the surface soils and rocks Established vegetation cover can arrest the fall of rock and soil Vegetation will thrive along natural seepage horizons/ springs and extract groundwater Tall trees to be avoided due to wind-throw
Lithological / landslide benches	May or may not be accessible Soils / suitable Medium to high cost to implement	Trees and cover plants will extract water reducing soil moisture balance and groundwater levels improving stability Trees will anchor / bind the shallow soil / debris on lithological benches and attenuate debris / rock falls run out from above Trees unlikely to strengthen landslide benches as shear surfaces are deep below root ball. Trees will also add load to the blocks which may counteract the benefit of water extraction
Talus / scree / debris	Generally accessible Soil / suitable Scree / less suitable Low to medium cost	Trees can bind the loose soil and rock and extract groundwater Wooded talus slopes will have greater stability Dense and staggered tree planting can attenuate rockfall acting as a natural barrier Loading and excess groundwater can lead to failures Erosion and cutting of talus can cause failures Low cover crop less effective

4. Suitability List of Trees and Ground Cover Species

Use of tree / cover vegetation to stabilise cliffs should not adversely impact local ecology or environmental interests / designations provided native species are specified and planted. The addition of cover crops and trees will in most cases improve or create new habitats and contribute significantly to biodiversity net gain.

Tree / cover planting schemes should, however, be designed by competent specialists combining knowledge and experience of coastal cliffs stability, ecology and landscaping. Planting designs should detail methods of access to the site, be informed by local survey/audit of the local native trees and cover plants for selection of suitable species, spacing and quantities, and the methods of planting. Safety must be considered at all stages of design and installation with due attention to risks of working at height and upon unstable and soft ground, and the associated hazards of rock falls and landslides.

Table 3. Tree and ground cover plant species suitable for coastal cliffs*

Tree / Bush Species	Ground Cover Species
Snowberry – Symphoricarpos albus	Periwinkle – Vince minor
Spindle – Euonymus europaeus	Thrift – Armeria maritima
Spindle – Euonymus alatus	Creeping phlox – Phlox subulate
Wild rose – Rosa rugosa	Sea Campion – Silene uniflora
Gorse – Ulex species	Rock Samphire – Crithmum maritimum
Blackthorn – Prunus spinosa	Sea Lavender – Limonium binervosum
Hawthorn – Crataegus monogyna	Common Scurvygrass – Cochlearia officinalis
Tamarix tetrandra	Grasses
Sea Buckthorn – Hippophae rhamnoides	Thyme
Buddleia davidii	
Griselinia littoralis	
Mahonia species	
Cotoneaster horizontalis	
Willow (Salix caprea, salix cinerea)	
Dogwood (Cornus spp.)	
Holm Oak Quercus ilex	

*The list is provided in no particular order. Selection of suitable species for specific coastal sites should be based on local surveys of native plant stock by a competent person.

Table 3 provides a select list of tree and cover plant species considered suitable to enhance the stability of coastal cliffs and slopes. The list below is based on the author's knowledge of tree and ground cover species found on the coastal cliffs of southern England, including Swanage and Charmouth. Additional information on species suitable for coastal environments can be found via Kew Royal Botanic Gardens and unvetted sites such as Flora and Fauna of the UK.

5. Cliff Vegetation Design and Installation Guidance

The following high level guidance is provided to inform the design and installation methods of cliff vegetation schemes.

5.1 Basis of Design and Installation

The **requirement** for cliff vegetation should be clearly stated and informed by appropriate surveys and assessment of the site and surrounding cliffs. This should include information about the area to be treated, the cliff morphology (slope profile and features e.g. scars, landslide benches etc), geology and soils, groundwater seepages, existing vegetation assemblage of adjacent cliffs and the site stability history where known.

Detailed assessment of the historical and current stability and whether the site can be safely accessed to install the planting scheme are key to deciding whether investment in cliff vegetation is worthwhile. A key consideration is whether vegetation planting could improve the stability of the site in the short and long-term through the establishment of shallow root strengthening and the removal of groundwater. If the cliff is subject to recent activity such as cliff falls or landslides, it is unlikely the cliff can be safely accessed or that vegetation planting will be successful given the ongoing movement and damage arising from cliff instability. Specialist advice by a competent person such as a chartered geologist should be sought.

It is not possible to measure or calculate the potential improvement to the stability of the cliffs from vegetation planting (see Section 2) with any certainty or guarantee meaning that there will always be inherent risk that vegetation on its own may not work or be short lived. However, compared to relatively high-cost engineering stabilisation options, vegetation planting has potential to achieve a high benefit to cost ratio and provide a nature-based solution to improve the stability of cliffs.

The **scope** of the planting scheme should be clearly identified including the site and area to be treated, the methods of installation and the planting scheme design. The scope may comprise treatment of an entire bare cliff section or targetted sections of bare cliff which may involve different methods of planting, as follows:

- seed spreading
- laying of pre-seeded matting
- planting of bare root whips/saplings, and
- planting of plug/potted trees

As stated above, consideration of the specific cliff morphology, geology and soils, groundwater, existing vegetation assemblage and the site stability history are important considerations when defining the scope and methods of planting. Each site would need to be considered on its merits and appropriate selection of species and design of planting schemes developed by a competent person.

There are preferred windows or **planting seasons** for tree and ground cover crops. These include late autumn / early winter i.e. November, and spring i.e. March. These periods are preferred as they provide optimum conditions for seed to germinate and plant roots to take hold whilst soil moisture and ground conditions are optimum.

5.2 Safe Access Methods

Safe access for cliff planting schemes is imperative. Various methods might be considered depending on the specific access constraints and requirements of the planting scheme, including the following:

- Use of drones (seed drop only)
- Scaffolding
- Cherry picker, mobile elevating work platforms (MEWPs) or boom lifts
- Rope access
- No specific safe access requirement

Use of **drones for seed dropping** over large inaccessible areas has been pioneered by the Woodland Trust in southwest England to restore the region's lost temperate rainforests. The drone technology specification comprises: 110kg drone weight, 58kg payload of seeds, flight altitude of several metres above ground, coverage of 10 hectares in 8 hours. The advantages include access to steep, remote, or unsafe terrain; faster and cheaper than manual planting of large areas; reduces safety risks of contractors' staff.

Use of **scaffolding** may be appropriate in certain circumstances such as access to vertical cliff faces from a secure base. Cantilevered scaffolding might be considered in situations where no secure base is present; they are deemed non-standard scaffolding and require bespoke design and compliance with standards. All scaffolding work must be carefully planned, supervised, and executed safely. Platforms over 2m require edge protection (guardrails, toe boards). Under CDM regulations scaffolding must be designed and risk-assessed as part of overall project planning. Employers must ensure safe working environments and proper training of staff.

Cherry pickers, also known as mobile elevating platforms (MEWPs) or boom lifts come in various configurations suited to different tasks. They can reach to over 50m height and outreach to over 20m, with various power options. For ground engineering tasks, especially those involving access to elevated or hard-to-reach areas, the following may be considered a) telescopic Boom Lifts for high-reach and stability on firm ground, b) spider Lifts for soft or uneven terrain, such as embankments or excavation zones and, c) towable Cherry Pickers for flexibility across multiple sites with quick setup. Use of cherry pickers is governed by several UK regulations with associated safety measures, training and certification.

Rope access is a method of working at height using ropes, harnesses, and associated equipment to reach difficult or elevated areas. It is widely used for inspections and engineering tasks where scaffolding or MEWPs are impractical. Use of rope access methods is covered by the Work at Height Regulations 2005, BS7985 Code of Practice and IRATA training certification and guidelines.

Some coastal cliffs may not require any specific access requirements where safe access may exist from public rights of way or private access such as vehicle tracks, paths and stairways. Nevertheless, it is recommended that a detailed risk assessment and safe system of work is prepared as part of the design of any cliff planting scheme and that recommended mitigation and personal protective equipment (PPE) are adopted prior to mobilisation and installation.

5.3 Plant Stock

Table 3 provides a list of tree and ground cover plant species suitable for coastal cliff environments. Depending on the requirement, design and methods of access and planting, plant stock will need to be ordered via a local or national supplier. It is recommended that early contact and discussion is made with several suppliers as it may be the case that the selection of plant species and quantity of stock may be limited and require separate orders to be fulfilled. In the case of bare rooted tree whips, these will only be available at certain times of year i.e. November and March. Rooted tree stock will be available year round, but as with all planting schemes, installation should coincide with the prime growing seasons (Spring and late Autumn) to ensure the best chances of success.

5.4 Installation Methods

The choice of installation method will depend on the project requirement, specific cliff morphology and safe access for planting. For targeted planting schemes it may be necessary to conduct enabling works to establish vehicular and pedestrian access to and from sites and to prepare the ground for planting.

Planting of inaccessible cliffs and large areas will be prohibitive for planting by machine or by hand. The use of **remote operated drones for spreading seed** offers a relatively new and innovative approach pioneered by the Woodland Trust. Whilst this approach has not specifically been deployed on coastal cliffs it has potential to achieve good results. There are a few constraints that need to be considered using this method, as follows:

- Seed is unlikely to deposit or remain on near-vertical cliffs and scarp slopes > 50°
- Germination is unlikely to be uniform and most successful on flushes and moist ground creating clusters of vegetation; success rate is estimated to be <25% with potential high wastage of seed
- Compliance with UK drone regulations specifically the use of heavy lift drones over private property, privacy and trespass (nuisance), GDPR and civil action
- Optimum flying conditions will be restricted to calm days with low wind speeds <10m/s to operate the drone and ensure controlled spreading of seed
- Obstructions imposed by the cliffs morphology and existing vegetation may impede line of sight, manoeuvrability and access of the drone to confined areas (i.e. beneath cliffs and shielded by existing dense trees and vegetation), and positioning to within several metres of the ground surface

Use of **pre-seeded matting** is a proven bioengineering method of vegetation establishment on slopes e.g. cut and fill slopes and soil nail and meshing of cliffs that supports biodiversity; success rates can be greater than 70% and up to 95% within the first year. Forest Research UK highlights that bioengineering methods are particularly effective for shallow landslides with added ecological benefits. For cliffs, pre-seeded matting would normally be applied as a supplementary measure to structural stabilisation solutions such as rock anchors and soil nails where the matting is securely fastened to cliffs and slopes. It is rarely used alone but provided the matting can be securely fastened to the cliff/area to be treated, the method offers some advantages and considerations including:

- Allows complete coverage of area to be treated providing protection from surface erosion and sediment runoff i.e. erosion control
- Enhances root development, soil cohesion and ecological restoration
- Provides aesthetic and environmental value.
- The matting is biodegradable (e.g. Coir, jute or straw), water absorbing and provides mulch/ bedding structure for seeds to germinate and establish; can be combined with live staking to add to the strengthening and advance colonisation of the matting
- Matting can be secured with biodegradable or steel staples at regular intervals (typically every 1–1.5 m)
- Inspection and maintenance can monitor vegetation growth and identify loose sections to be re-anchored and supplemented with replanting if necessary

Planting **bare root whips** is a widely used and cost effective technique in UK bioengineering and landscaping, especially for hedgerows, woodland creation, and slope stabilisation. Bare root whips are young, unbranched trees or shrubs, typically 1–2 years old, sold without soil around their roots. They're economical, easy to transport, and ideal for mass planting with a high rate (>90%) of success. Ideal season for planting is between November to March, during the dormant period, with an extended window to April or May if stock is cold-stored and weather permits.

Planting should be avoided when soil is frozen, waterlogged and during heavy frost. On windy or sunny days roots can dry out quickly. Other considerations for installation are provided below:

<u>Storage Before Planting-</u> Keep roots moist and cool; store in a plastic bag in a shaded, frost-free place; for longer delays, heel in by burying roots in loose soil.

<u>Site Preparation-</u> Drill/dig a hole or trench 1/3 larger than the root spread; avoid planting deeper than the original soil mark on the stem.

<u>Planting-</u> Soak roots in water for up to 1 hour before planting; spread roots evenly in the hole; backfill with soil, firm gently to eliminate air pockets; double row spacing 5 plants per metre, staggered in a zigzag; single row spacing 30cm apart; use Rootgrow (mycorrhizal fungi) and soil moisture retention gels or mix with gypsum to boost root establishment.

<u>Protection-</u> Insert a bamboo cane for support; wrap a guard around the whip and cane to protect from animals; apply mulch to suppress weeds and retain moisture.

<u>Watering-</u> Recommended only at time of planting and for a short period to establish plants such as watering during dry spells in the first year.

Planting **rooted (potted) plants** can be an effective approach for stabilising smaller, targeted areas of cliff or slope with the highest success rate (>95%). Similar to the use of whips, this method is a well-established bioengineering technique that contributes to slope stability, mitigates erosion, and enhances ecological resilience.

Rooted plants, typically aged between 3 to 5 years, offer immediate ground cover and a higher likelihood of establishment success due to their intact root systems and accompanying soil which will take hold and grow quicker than other methods. While the general planting principles for whips also apply to rooted plants, the key distinction lies in the installation requirements. Rooted specimens necessitate more difficult delivery and handling and require larger planting holes or trenches, which often involve the use of wide-diameter drills or augers and result in greater soil displacement.

5.5 Monitoring and Maintenance

Monitoring of the growth and success of cliff vegetation planting schemes can be conducted both physically or remotely depending on access. Use of visual inspections, photography, aerial (drone) surveys all have their advantages, and a combination of methods is probably best. The cycle of monitoring and maintenance should follow the growing seasons with bi-annual surveys recommended for comparison e.g. August/September (peak growth) and February/March (die-back). The main indicator of success will be the health and establishment of cover, both spacing of plants and density of canopy, but tree/bush height can also be used as a measure of growth. The penetration depth of root systems can only be measured by excavation of select plants which is not recommended due to its destructive nature unless considered absolutely necessary.

Based on the bi-annual surveys it is recommended a report is prepared by a competent person to document the health of the scheme, identify maintenance, lessons learnt and recommendations for future schemes.

5.6 Other General Guidance

Previous published guidance for developers and homeowners has stated the need to avoid the removal of trees and bushes from steep slopes, as in many cases the vegetation acts to bind the soil and reduce the likelihood of slope instability.

It is recommended that 'Advice to Homeowners' should include:

> *"if you are concerned about the removal of trees or vegetation from adjacent slopes seek professional advice or contact the local authority".*

This voluntary code should be encouraged to increase awareness of the issue and prevent the inadvertent removal of trees and vegetation.

It is particularly important that future development proposals take full account of the possible impact of site clearance works involving the removal of trees. Development proposals should aim to minimise site clearance and tree felling and provision should be made for the replanting of trees wherever possible.

There are other reasons why trees might be protected i.e. conservation interests and, indeed, Local Councils have a legal duty to protect trees. Tree Preservation Orders can be used to strengthen a condition that is part of a planning permission, and to protect groups of trees that are in danger of being cut down. Work which is not exempt, and which is carried out without the formal consent of the Council is illegal. The Council may prosecute offenders, and the Magistrates may impose fines for each tree if convicted of an offence.

With reference to Table 2, it would be possible to delineate areas on the 'Geomorphology' and 'Planning Guidance' maps where trees and vegetation provide a significant benefit to slope stability. These areas could be used to define limits of Tree Preservation Orders in order to protect and maintain their contribution to slope stability.

There have been incidences where landowners have removed trees and vegetation that will have increased the susceptibility of sites and adjacent land to slope instability. In these instances, the landowners should be advised of the possible consequence of their actions and where the consequences are believed to be significant, they should be asked to stop to allow further assessment. There will always be cases where landowners choose to carry on regardless which may require serving of enforcement and stop notices under statutory orders (i.e. tree preservation orders) or other statutory powers, which can lead to prosecution.

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Appendix A. Zonation Maps

Suitability of tree and vegetation planting sites at Swanage and Charmouth