Check for updates

BRIEF REPORT

REVISED Ten years of vegetation recovery following Nature-based restoration of landslide scars in the Azores

[version 2; peer review: 1 approved, 1 approved with reservations]

Previously titled: "Landslide ecological restoration using Nature-based Solutions: A case study in the Azores"

Tarso de Menezes Macedo Costa[1,2], Lourdes Peñil[3-6], Rui Botelho[1], Azucena de la Cruz[1]

[1]Portuguese Society for the Study of Birds, Nordeste, Azores, 9630-147, Portugal
[2]Faculty of Sciences and Technology, University of the Azores, cE3c—Centre for Ecology, Evolution and Environmental Changes, Ponta Delgada, Azores, 9500-321, Portugal
[3]Forest Research Center, School of Agriculture, University of Lisbon, Lisbon, 1349-017, Portugal
[4]Department of Forestry Engineering, University of Córdoba, Córdoba, 14075, Spain
[5]Rua do Contador nº 23, Regional Directorate for Forest Resources and Spatial Planning, Ponta Delgada, São Miguel, Portugal
[6]Regional Directorate for Forest Resources and Spatial Planning, Rua do Contador nº 23, 9500–050, Ponta Delgada, São Miguel, Portugal

v2 **First published:** 30 Apr 2026, **6**:139
https://doi.org/10.12688/openreseurope.23526.1
Latest published: 25 Aug 2026, **6**:139
https://doi.org/10.12688/openreseurope.23526.2

Abstract

Landslides are common in the Azores due to steep topography, volcanic soils, and high rainfall, creating disturbed areas that are often colonized by invasive plant species and contribute to habitat degradation within the Pico da Vara/Ribeira do Guilherme Special Protection Area (São Miguel Island). In 2015, as part of the LIFE+ Lands of Priolo project, Nature-based Solutions (NbS) combining bioengineering measures and hydroseeding with native species were implemented to restore five landslide scars. This study evaluates vegetation recovery over a ten-year period. Hydroseeding species accounted for 82.5% of total germination, although establishment success varied substantially among taxa. After ten years, restored slopes were dominated by native vegetation, with a mean native cover of 87.9%, while exotic species richness and cover were significantly lower than in control areas. Only *Calluna vulgaris* and *Festuca francoi* remained abundant among the hydroseeded species, whereas *Sphagnum* sp. and *Woodwardia radicans* became dominant through natural colonization. Multivariate analyses revealed significant differences in plant community composition between restored and control slopes. The results suggest that long-term vegetation recovery

Open Peer Review

Approval Status ? ✓

	1	2
version 2 (revision) 25 Aug 2026	? view	✓ view
version 1 30 Apr 2026	? view	? view

1. **F. A. SAMIUL ISLAM**, Uttara University, Dhaka, Bangladesh

2. **Nunzio Marrone**, University of Naples Federico II, Napoli, Italy

Any reports and responses or comments on the article can be found at the end of the article.

resulted from the combined effects of active restoration measures and natural ecological succession. This study provides rare long-term evidence of NbS performance in a protected island area and highlights their potential to support habitat restoration following landslide disturbance.

Keywords
biodiversity, conservation, hydroseed, NbS, Azores

HE This article is included in the Horizon Europe gateway.

Corresponding author: Tarso de Menezes Macedo Costa (tarso.costa@spea.pt)

Author roles: Costa TdMM: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Writing – Original Draft Preparation; **Peñil L**: Investigation, Methodology; **Botelho R**: Funding Acquisition, Project Administration; **de la Cruz A**: Funding Acquisition, Project Administration, Writing – Review & Editing

Competing interests: No competing interests were disclosed.

Grant information: This project has received funding from the Horizon Europe Framework Programme through the SpongeBoost project under grant agreement No [101112906]
The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Copyright: © 2026 Costa TdMM *et al*. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

How to cite this article: Costa TdMM, Peñil L, Botelho R and de la Cruz A. **Ten years of vegetation recovery following Nature-based restoration of landslide scars in the Azores [version 2; peer review: 1 approved, 1 approved with reservations]** Open Research Europe 2026, **6**:139 https://doi.org/10.12688/openreseurope.23526.2

First published: 30 Apr 2026, **6**:139 https://doi.org/10.12688/openreseurope.23526.1

REVISED **Amendments from Version 1**

This version has been substantially revised following the reviewers' comments. The manuscript was reframed to focus on long-term vegetation recovery following Nature-based restoration rather than solely on the performance of hydroseeding. The Introduction was expanded with recent literature on Nature-based Solutions, ecological restoration, protected areas, and Azorean vegetation, providing a stronger scientific context.

The Methods section was extensively revised to improve reproducibility, including a detailed description of the restoration interventions, landslide types, vegetation sampling design, hydroseeding assessment, and statistical analyses. The analytical approach was also strengthened by shifting from slope-level descriptive comparisons to plot-level inferential analyses, including Mann–Whitney tests, NMDS, PERMANOVA, PERMDISP, CAP, SIMPER, and Indicator Species Analysis.

The Results section was reorganized to present hydroseeding performance separately from long-term vegetation recovery, with greater emphasis on native and exotic vegetation, statistical significance, and multivariate community patterns. Figures and captions were updated accordingly.

The Discussion was substantially rewritten to provide a more balanced interpretation of the results, explicitly distinguishing the contribution of hydroseeding from natural ecological succession, moderating conclusions where appropriate, and acknowledging study limitations. The manuscript also clarifies that restoration success is primarily reflected by the recovery of native habitats and the reduction of invasive alien species, rather than by species richness alone. Overall, these revisions considerably strengthen the scientific rigor, transparency, and ecological interpretation of the study.

Any further responses from the reviewers can be found at the end of the article

Introduction

Nature-based Solutions (NbS) have emerged as a promising approach to address environmental challenges by combining ecosystem restoration with risk reduction and climate adaptation objectives (European Commission, 2021; Raymond et al., 2017). In landslide-prone environments, NbS can contribute to slope stabilization, erosion control, runoff regulation, and habitat recovery through the integration of bioengineering techniques and ecological restoration measures. Recent studies have highlighted the importance of selecting NbS according to ecosystem characteristics, geomorphological conditions, and restoration objectives. Frameworks integrating ecological and engineering criteria demonstrate that combinations of bioengineering structures, runoff management measures, and revegetation techniques can support ecosystem recovery while simultaneously addressing hydrogeomorphological risks (Arce-Mojica et al., 2019; Sarwar et al., 2025).

Beyond the direct loss of soil and vegetation, landslides may create long-lasting ecological disturbances by disrupting native plant communities and facilitating the establishment of IAS. This challenge is particularly relevant in oceanic islands, where many endemic species occupy restricted environmental niches and are vulnerable to habitat degradation and fragmentation. In the Azores, future climate projections suggest substantial reductions in suitable climatic conditions for many native and endemic species, highlighting the importance of habitat restoration and ecological connectivity for long-term biodiversity conservation (Ferreira et al., 2016).

The natural vegetation of the Azores is organized along distinct elevational gradients, forming characteristic vegetation belts associated with climatic and environmental conditions. High-elevation habitats are typically dominated by native communities composed of species such as *Calluna vulgaris*, *Erica azorica*, *Juniperus brevifolia*, and bryophyte-rich assemblages, which represent important conservation targets due to their ecological uniqueness and role in supporting endemic biodiversity (Elias et al., 2016). Consequently, restoration initiatives in the Azores aim to recover native habitats and their characteristic vegetation, with particular emphasis on reversing habitat degradation and invasive species impacts.

Within the Pico da Vara/Ribeira do Guilherme Special Protection Area (PV/RG SPA), landslides represent an important source of habitat disturbance and may facilitate the spread of invasive species into priority habitats. Restoration actions implemented under the LIFE+ Lands of Priolo project therefore combined bioengineering measures and native species revegetation to stabilize landslide scars and promote ecosystem recovery. Restoration of degraded habitats may complement protected area management by increasing the availability and connectivity of native habitats within conservation landscapes, where biodiversity representation can be improved through spatially targeted conservation actions (Vergilio et al., 2016).

This study evaluates ten years of vegetation recovery following the implementation of NbS in landslide scars within PV/RG SPA on São Miguel Island (Azores). Specifically, we assessed (i) the short-term performance of hydroseeding

through germination and establishment success, (ii) long-term vegetation composition, biodiversity patterns, and differences between restored and reference slopes, and (iii) the relative contribution of active restoration measures and natural colonization processes to ecosystem recovery.

Methods

Nature-based restoration interventions

Five landslide scars (D1–D5) located within PV/RG SPA were restored in 2015 under the LIFE+ Lands of Priolo project (Figure 1). Three landslides (D1–D3) were classified as shallow failures, whereas D4 and D5 involved deeper soil displacement and required slope regrading using heavy machinery before restoration interventions were implemented.

Restoration planning included topographic surveys, slope characterization, and the preparation of planting and engineering designs. Initial works focused on the removal of IAS using mechanical and chemical control methods. Subsequently, a combination of bioengineering techniques was implemented, including live crib walls, living grids, palisades, erosion-control barriers, and bioswales constructed using natural materials such as logs, stones, and wooden stakes (Figure 2). These measures were designed to facilitate vegetation establishment, reduce surface runoff concentration, and support ecological restoration processes.

Hydroseeding was applied using locally collected native species from the PV/RG SPA. The seed mixture consisted of *Calluna vulgaris* and *Erica azorica* (1 kg per 100 m^2 each), and *Festuca francoi*, *Leontodon rigens*, *Luzula purpureosplendens*, and *Hypericum foliosum* (0.25 kg per 100 m^2 each). Following implementation, restoration areas were maintained quarterly during the first three years to control IAS and support vegetation establishment.

Hydroseeding assessment

Hydroseeding performance was evaluated one year after implementation using six randomly positioned 1 × 1 m plots distributed across the restored landslides. For each hydroseeded species, the number of established individuals was recorded and compared with the estimated number of seeds applied per square meter. Germination rates were calculated as the proportion of established individuals relative to the estimated seed density.

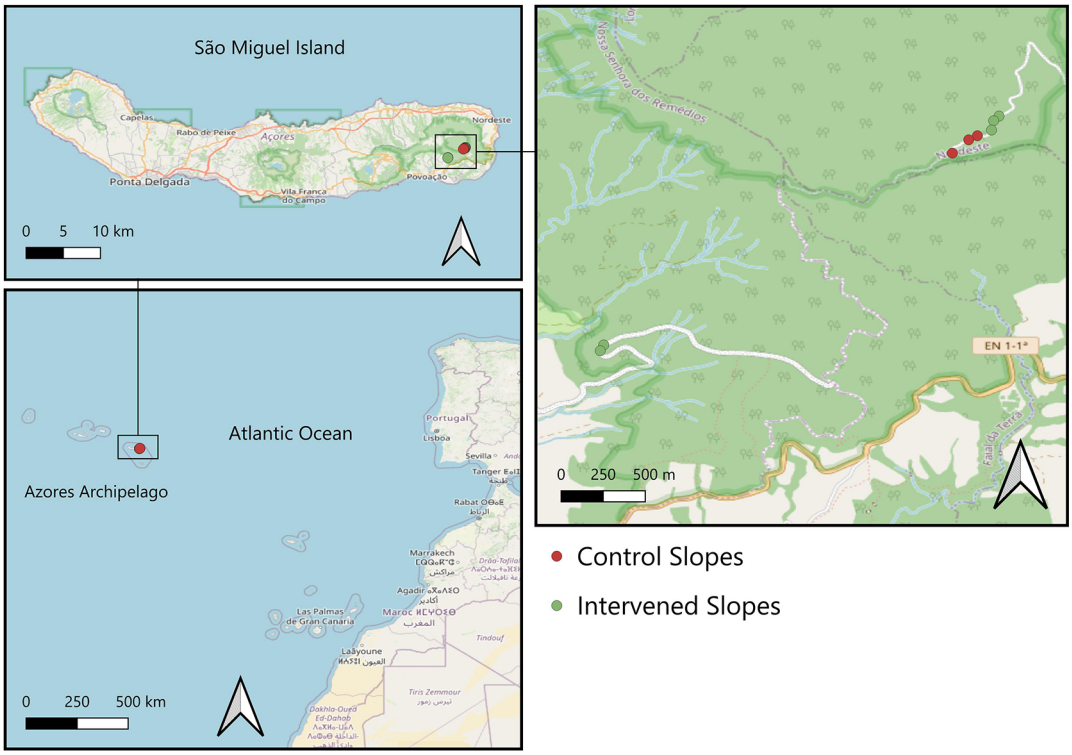

Figure 1. Location of the studied slopes, in the Pico da Vara/Ribeira do Guilherme SPA (São Miguel, Azores, Portugal).



Figure 2. Slope reprofiling using heavy machinery, followed by the installation of NBS (including live crib walls and bioswales, shown here) constructed with natural materials and iron rods, and subsequent hydroseeding with native species.

Vegetation monitoring

To evaluate long-term vegetation recovery, 24 plots (1 × 1 m) were surveyed in 2024. Fifteen plots were located within restored landslides (three plots per restored landslide), while nine plots were established on three non-restored reference slopes (C1–C3), representing a gradient of vegetation conditions ranging from mixed native–invasive communities to predominantly native vegetation. Reference slopes were selected within the same protected area and under comparable environmental conditions, including elevation, climate, and surrounding vegetation, to provide ecological benchmarks for restoration assessment (Morton, 2009).

Vegetation cover in percentage was visually estimated for all vascular plant and bryophyte species within each plot. Species were subsequently classified as native or exotic according to regional floristic references. For each plot, species richness, total vegetation cover, native species richness, exotic species richness, native cover, exotic cover, and the proportional contribution of native and exotic vegetation were calculated.

Statistical analyses

Differences between restored and reference plots were assessed at the plot level (n = 24). Because most variables did not meet normality assumptions, comparisons of native and exotic richness and cover metrics were performed using Mann–Whitney U tests. Effect sizes were calculated using the rank-biserial correlation coefficient (r) and classified following conventional thresholds.

Plant community composition was analysed using Bray–Curtis dissimilarities. Non-metric multidimensional scaling (NMDS) was used to visualize differences among plots. Permutational multivariate analysis of variance (PERMANOVA; 9,999 permutations) was applied to test for differences in species composition between restored and reference plots, while homogeneity of multivariate dispersion was evaluated using PERMDISP. Canonical Analysis of Principal Coordinates (CAP) was used to further assess group separation.

Species contributing most strongly to compositional differences were identified using Similarity Percentage Analysis (SIMPER). Indicator Species Analysis (IndVal) was performed to identify species significantly associated with restored or reference conditions. All statistical analyses were conducted in R version 2026.07.1 using the packages vegan, indicspecies, rstatix, and tidyverse.

Results

Hydroseeding performance

All species included in the hydroseeding mixture germinated during the first year following restoration. Germination rates varied substantially among species (Figure 3), with *Leontodon rigens* (0.037 plants per seed applied), *Festuca*

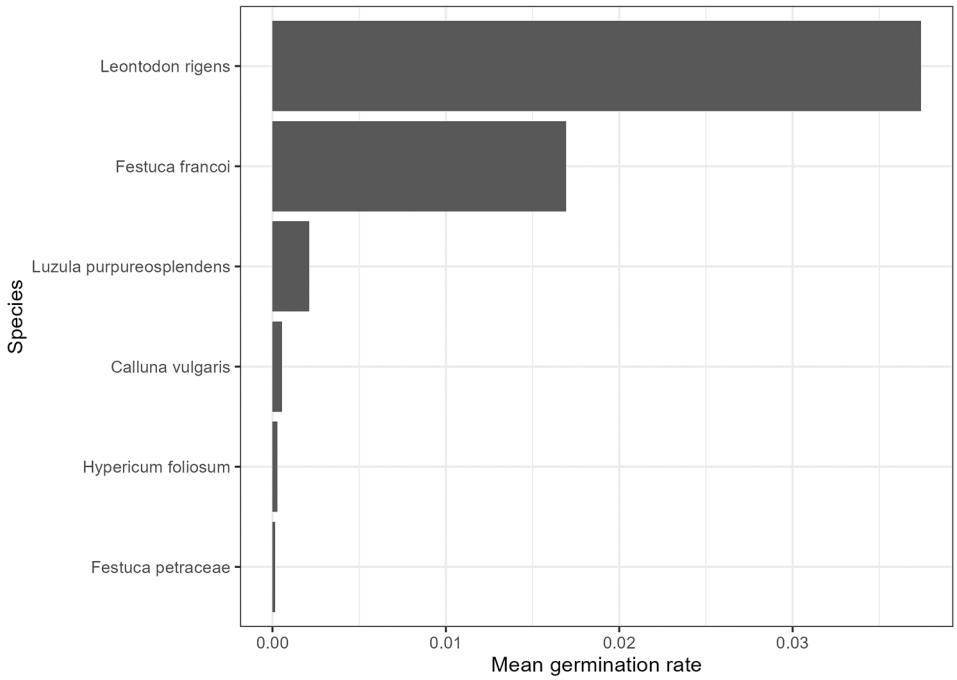

Figure 3. Germination rates of native species used in the hydroseeding mixture one year after implementation.

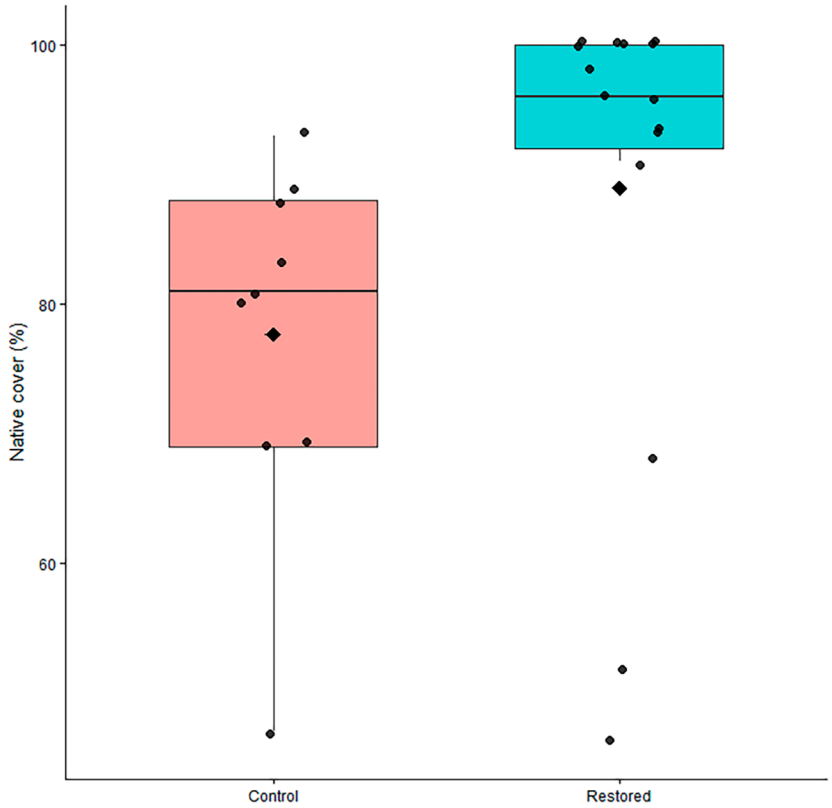

Figure 4. Percentage cover of native species in restored (n = 15) and control plots (n = 9) ten years after restoration. Points represent individual 1 × 1 m plots, boxplots show the median and interquartile range, and whiskers indicate the range of observed values.

francoi (0.017), and *Luzula purpureosplendens* (0.002) showing the highest establishment success. In contrast, *Calluna vulgaris*, *Hypericum foliosum*, and *Festuca petraceae* exhibited very low germination rates (<0.001). Ten years after restoration, hydroseeded species remained important components of the vegetation, particularly *L. rigens* (mean abundance = 187 individuals m^{-2}) and *F. francoi* (63.5 individuals m^{-2}), although several abundant native species, including *Sphagnum* sp. and *Woodwardia radicans*, established through natural colonization.

Native and exotic vegetation

Restored plots were characterised by a significantly lower richness of exotic species than control plots (Mann–Whitney U = 117, p = 0.003, r = 0.62). Native species richness did not differ significantly between treatments (U = 70, p = 0.90,

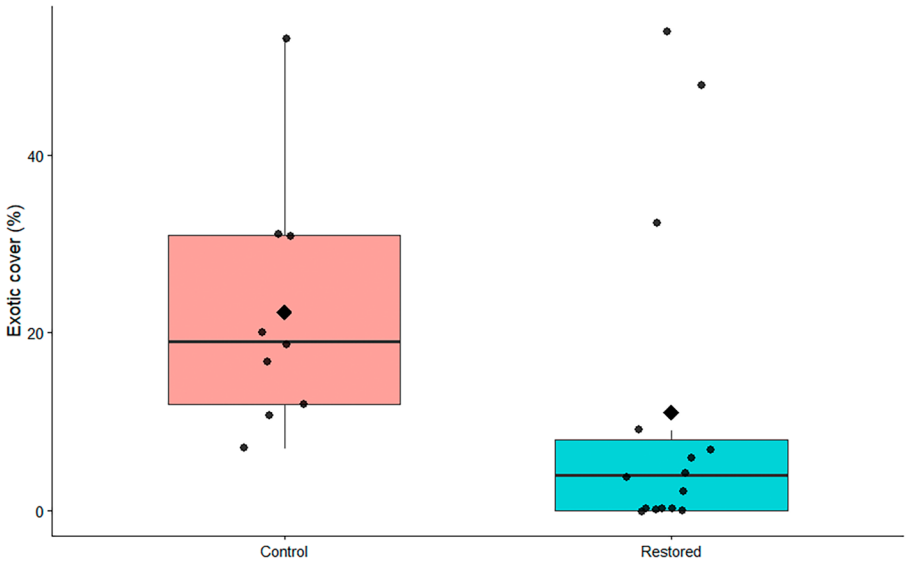

Figure 5. Percentage cover of exotic species in restored (n = 15) and control plots (n = 9) ten years after restoration. Points represent individual 1 × 1 m plots, boxplots show the median and interquartile range, and whiskers indicate the range of observed values.

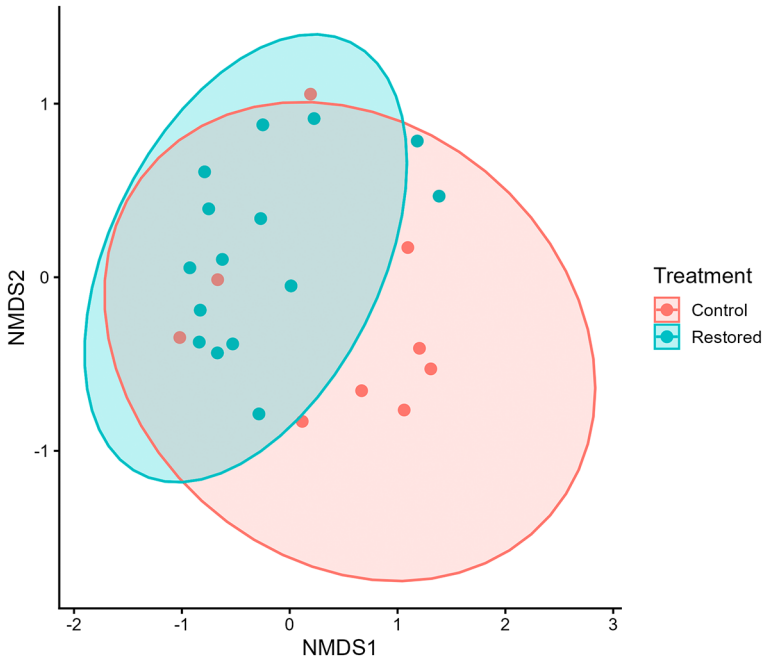

Figure 6. Non-metric multidimensional scaling (NMDS) ordination of plant community composition in restored and control plots based on Bray–Curtis dissimilarity. Each point represents a 1 × 1 m vegetation plot.

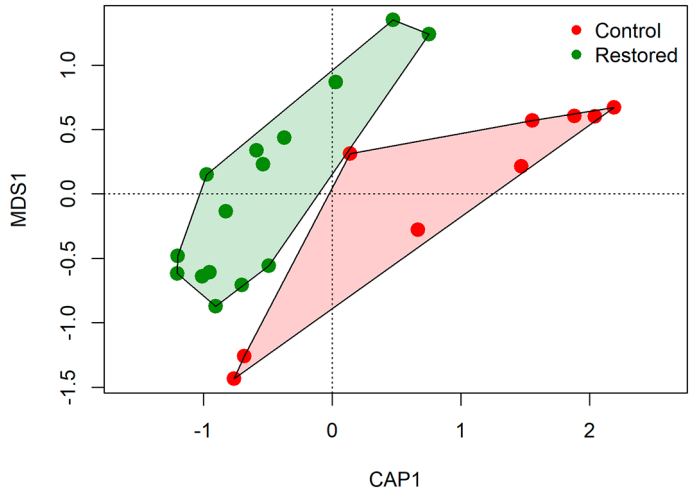

Figure 7. Canonical Analysis of Principal Coordinates (CAP) of plant community composition in restored and control plots based on Bray–Curtis dissimilarity. Each point represents a 1 × 1 m vegetation plot.

r = 0.03). However, native vegetation cover was significantly higher in restored plots (U = 27.5, p = 0.018, r = 0.49), while exotic vegetation cover was significantly lower (U = 108.5, p = 0.015, r = 0.50). Similarly, the proportional contribution of native species was significantly greater in restored plots (p = 0.015), whereas the proportion of exotic vegetation was significantly reduced.

Restored plots exhibited high native vegetation cover (mean = 87.9 ± 15.4%). The most abundant native taxa were *Sphagnum* sp. (20.0%), *Calluna vulgaris* (19.6%), *Woodwardia radicans* (10.9%), and *Festuca francoi* (10.2%). Among these, only *C. vulgaris* and *F. francoi* were included in the hydroseeding mixture. The most abundant exotic taxa were *Polygonum capitatum* (3.2%), *Poa* sp. (2.9%), *Dicksonia antarctica* (1.6%), and *Erigeron* sp. (1.2%). Figures 4 and 5 illustrate the percentage cover of native and exotic species recorded in restored and control plots ten years after restoration.

Community composition analyses

Non-metric multidimensional scaling (NMDS) revealed partial separation between restored and control plots (stress = 0.175) (Figure 6). PERMANOVA confirmed significant differences in plant community composition between treatments ($F = 2.75$, $R^2 = 0.11$, $p = 0.012$). Multivariate dispersion did not differ significantly between groups (PERMDISP, $p = 0.517$), indicating that the observed compositional differences were not driven by unequal within-group variability. Canonical Analysis of Principal Coordinates (CAP) further supported the distinction between restored and control communities ($p = 0.014$) (Figure 7).

Discussion

Ten years after restoration, all restored landslide scars remained fully vegetated, and no additional landslide events were recorded within the monitored sites. Although slope stability and erosion rates were not directly quantified, the persistence of vegetation cover and the continued functionality of the bioengineering structures indicate successful long-term establishment of the restoration interventions. Restored plots were characterized by significantly higher native vegetation cover and significantly lower exotic species richness and cover than control plots, suggesting that the implemented NbS contributed to the recovery of native plant communities following landslide disturbance. These findings are consistent with the role of NbS in supporting ecosystem recovery and biodiversity conservation after environmental disturbances (Ommer et al., 2022).

Enhancing biodiversity is a recognized strategy to address climate resilience and societal challenges through NbS (Raymond et al., 2017). In the PV/RG SPA, IAS represent one of the main threats to native habitats, particularly after landslides, which create open areas susceptible to colonization by opportunistic species (Costa et al., 2013). The significantly lower richness and cover of exotic species observed in restored plots indicate that restoration interventions may help reduce invasion pressure while promoting the recovery of native vegetation. Such outcomes are particularly relevant for the conservation of the endemic Azores Bullfinch (*Pyrrhula murina*), whose population (~1,000 individuals) remains strongly influenced by habitat quality and IAS impacts (Costa et al., 2023; Heredia et al., 1996; Ramos, 1996). Species such as *Woodwardia radicans* are also ecologically relevant because fern fronds constitute an important food

resource for the Azores Bullfinch (Ramos, 1994). By facilitating the re-establishment of native vegetation, restoration measures may contribute to improved habitat quality and ecological connectivity, supporting conservation objectives under both the Natura 2000 framework and the EU Biodiversity Strategy for 2030 (European Commission, 2021; Eggermont et al., 2015).

Monitoring and evaluation are crucial for assessing NbS effectiveness (Sarabi et al., 2019; Kumar et al., 2021a). The hydroseeding assessment demonstrated that although all seeded species germinated during the first year, establishment success varied substantially among species. *Leontodon rigens* and *Festuca francoi* showed the highest germination and long-term persistence, whereas several other hydroseeded species remained poorly represented after ten years. At the same time, species not included in the hydroseeding mixture, particularly *Woodwardia radicans* and *Sphagnum* sp., became dominant components of the restored vegetation. These findings suggest that long-term restoration outcomes resulted from the combined influence of active restoration measures and natural ecological succession rather than hydroseeding alone. Similar patterns have been reported in restoration studies where natural colonization processes play an important role in shaping vegetation trajectories after disturbance. The significant contribution of *Sphagnum* sp., *Calluna vulgaris*, *Luzula purpureosplendens*, *Woodwardia radicans*, and *Festuca francoi* to community differentiation further supports the importance of native species establishment during ecosystem recovery.

Multivariate analyses revealed significant differences in plant community composition between restored and control plots. Both PERMANOVA and CAP indicated clear compositional separation between treatments, while SIMPER identified a small group of native species as the principal contributors to these differences. Indicator Species Analysis identified five significant indicator species associated with control plots, including several invasive or non-target taxa, whereas no indicator species were associated with restored plots. Together, these results suggest that restoration promoted the development of plant communities that differ from those observed in non-restored slopes and are characterized by a stronger dominance of native vegetation.

Ecological indices indicated that native species richness did not differ significantly between restored and control plots. Nevertheless, restored plots supported significantly lower exotic species richness and cover and a higher dominance of native vegetation. Given that invasive alien species are among the main drivers of habitat degradation in the Pico da Vara/Ribeira do Guilherme SPA (Costa et al., 2013), these results suggest that restoration measures successfully promoted the recovery of native habitat conditions while reducing opportunities for invasion following landslide disturbance. While hydroseeding facilitates rapid vegetation establishment and surface protection, woody native species may provide additional long-term benefits for slope stabilization through deeper root penetration and greater soil reinforcement (Baltasar, 1988). The potential use of Azorean native trees in soil bioengineering techniques, such as live staking, remains largely unexplored and deserves further investigation. Evaluating the mechanical and ecological performance of these species could improve the effectiveness of future Nature-based restoration interventions in landslide-prone environments.

There remains a lack of widely accepted and standardized approaches for monitoring NbS performance (Kumar et al., 2021a, 2021b). Evaluating project success therefore depends on selecting indicators that are consistent with restoration objectives. In protected areas, biodiversity indicators provide valuable information on habitat recovery and vegetation development. However, a comprehensive assessment of NbS should also incorporate ecosystem services such as runoff regulation, water retention, erosion reduction, and climate resilience to fully capture intervention performance and benefits (Sarabi et al., 2019; Kumar et al., 2021a).

This study has several limitations that should be acknowledged. First, quantitative pre-restoration vegetation data were not available, preventing direct before–after comparisons and limiting the assessment of ecological trajectories through time. Second, the study evaluated a relatively small number of restored and reference slopes, which may limit broader generalization of the findings. Third, the study focused primarily on vegetation recovery and community composition, while ecosystem services such as runoff regulation, sediment retention, and geotechnical slope stability were not directly measured. Future studies integrating ecological, hydrological, and geomorphological indicators would provide a more comprehensive evaluation of NbS performance in landslide restoration contexts.

Despite these limitations, the ten-year monitoring programme provides valuable evidence regarding long-term vegetation recovery following NbS implementation in an island protected area. The results demonstrate that restoration interventions promoted native vegetation dominance, reduced exotic species representation, and facilitated the development of distinct plant communities. These findings contribute to the growing evidence base supporting NbS as effective tools for ecological restoration in disturbed landscapes and provide practical guidance for future restoration initiatives in the Azores and other island ecosystems. Restoration of degraded habitats may complement protected area management by

increasing the availability and connectivity of native habitats within conservation landscapes. In island systems such as the Azores, biodiversity representation can be improved through spatially targeted conservation actions that enhance habitat quality and reduce ecosystem degradation (Vergilio et al., 2016).

Ethics and consent

Ethical approval and consent were not required.

Use of generative AI

During the preparation of this manuscript, the authors used ChatGPT (OpenAI, GPT-5.5) to assist with language editing, improving clarity and readability, restructuring sections of the manuscript, refining the presentation of the methods and discussion, and preparing responses to peer-review comments. The tool was used solely as a writing and editorial assistant. It was not used to generate data, perform statistical analyses, interpret results, or make scientific decisions. All scientific content, analyses, interpretations, and conclusions were developed, verified, and approved by the authors, who take full responsibility for the final content of the manuscript.

Data availability statement

The datasets generated and/or analyzed during the current study are available in the Zenodo repository, [https://doi.org/10.5281/zenodo.19221757] under a CC-BY 4.0 license (Costa, T., 2026).

Data are available under the terms of the Creative Commons Zero "No rights reserved" data waiver (CC0 1.0 Public domain dedication).

Acknowledgments

The rehabilitation of the slopes using Nature-Based Solutions (NBS) in the Pico da Vara/Ribeira do Guilherme SPA was carried out under the LIFE+ Lands of Priolo project (LIFE12 NAT/PT/000527), supported by the LIFE Programme of the European Commission and the Government of the Azores.

References

Arce-Mojica TJ, Nehren U, Sudmeier-Rieux K, *et al.*: **Nature-based solutions (NbS) for reducing the risk of shallow landslides: Where do we stand?** *Int J Disaster Risk Reduct.* 2019; **41**: 101293.
Publisher Full Text

Baltasar CFA: **Contribuição para o estudo e caracterização geomorfológica de taludes e escarpas**. *Universidade de Évora*; 1988; 311 pp. MSc Dissertation.

Costa H, Bettencourt MJ, Silva CMN, *et al.*: **Invasive Alien Plants in the Azorean Protected Areas: Invasion Status and Mitigation Actions**. Foxcroft LC, Pyšek P, Richardson DM, *et al.*, editors. *Plant Invasions in Protected Areas: Patterns, Problems and Challenges.* Dordrecht, The Netherlands: Springer; 2013. 9789400777507.
Publisher Full Text

Costa T: Vegetation Hydroseeding and Monitoring Dataset. [Data set]. *International Symposium FloraMac 2025: Program & Abstracts.* Zenodo; 2026; p.10.
Publisher Full Text

Costa TdMM, Gil A, Timóteo S, *et al.*: **How Many Azores Bullfinches *(Pyrrhula murina)* Are There in the World? Case Study of a Threatened Species.** *Diversity.* 2023; **15**(5): 685.
Publisher Full Text

Eggermont H, Balian E, A JMN, *et al.*: **Nature-based solutions: New influence for environmental management and research in Europe.** *Gaia.* 2015; **24**(4): 243–248.
Publisher Full Text

Elias RB, Gil A, Silva L, *et al.*: **Natural zonal vegetation of the Azores Islands: Characterization and potential distribution.** *Phytocoenologia.* 2016; **46**(2): 107–123.
Publisher Full Text

European Commission: *Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners*; 2021.
Publisher Full Text

Ferreira MT, Cardoso P, Borges PA, *et al.*: **Effects of climate change on the distribution of indigenous species in oceanic islands (Azores).** *Climatic Change.* 2016; **138**: 603–615.
Publisher Full Text

Heredia B, Rose L, Painter M: *Globally Threatened Birds in Europe: Action Plans.* Strasbourg, France: Council of Europe; 1996; 9789287130662.

Kumar P, Debele SE, Sahani J, *et al.*: **Nature-based solutions efficiency evaluation against natural hazards: modelling methods, advantages and limitations.** *Sci Total Environ.* 2021a; **784**: 147058.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Kumar P, Debele SE, Sahani J, *et al.*: **An overview of monitoring methods for assessing the performance of nature-based solutions against natural hazards.** *Earth Sci Rev.* 2021b; **217**: 103603.
Publisher Full Text

Morton MH: **Applicability of Impact Evaluation to Cohesion Policy, Report Working Paper.** 2009.
Reference Source

Ommer J, Bucchignani E, Leo LS, *et al.*: **Quantifying co-benefits and disbenefits of Nature-based Solutions targeting Disaster Risk Reduction.** *Int J Disaster Risk Reduct.* 2022; **75**: 102966.
Publisher Full Text

Ramos JA: **Fern Frond Feeding by the Azores Bullfinch.** *J Avian Biol.* 1994; **25**: 344–347.
Publisher Full Text

Ramos JA: **Introduction of Exotic Tree Species as a Threat to the Azores Bullfinch Population.** *J Appl Ecol.* 1996; **33**: 710.
Publisher Full Text

Raymond CM, Berry P, Breil M, *et al.*: **A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas.** *Environ Sci Policy.* 2017; **77**: 15–24.
Publisher Full Text

Sarabi E, Han S, Romme Q, *et al.*: **Key enablers of and barriers to the uptake and implementation of nature-based solutions in urban settings: a review.** *Resources.* 2019; **8**(3): 121.
Publisher Full Text

Sarwar AN, Caramiello C, Pugliese F, *et al.*: **A framework for selecting Nature-based Solutions: applications and challenges at the catchment scale.** *J Environ Manage.* 2025; **394**: 127220.
PubMed Abstract | **Publisher Full Text**

Vergílio M, Fonseca C, Calado H, *et al.*: **Assessing the efficiency of protected areas to represent biodiversity: a small island case study.** *Environ Conserv.* 2016; **43**(4): 337–349.
Publisher Full Text

Open Peer Review

Current Peer Review Status: ? ✓

Version 2

Reviewer Report 11 September 2026

https://doi.org/10.21956/openreseurope.26787.r79696

© **2026 ISLAM F.** This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

?

F. A. SAMIUL ISLAM
Department of Civil Engineering, Uttara University, Dhaka, Dhaka, Bangladesh

I have carefully evaluated Version 2 of the manuscript together with the revisions made in response to the previous peer-review comments. I recognize that the authors have made substantial efforts to improve the manuscript. The revised version is clearer than the previous version. The manuscript now identifies the five restored landslides as D1-D5 and distinguishes shallow failures from deeper soil displacement. It also describes the major restoration measures, including live crib walls, living grids, palisades, erosion-control barriers, bioswales, and hydroseeding. The authors have also added inferential and multivariate analyses and have added a limitations section.
The reframing of the manuscript toward long-term vegetation recovery is also appropriate. The revised Discussion is more balanced regarding the contribution of hydroseeding and natural colonization. The manuscript now explicitly recognizes that species such as *Sphagnum* sp. and *Woodwardia radicans* became important through natural colonization. I also appreciate the authors' decision to acknowledge the absence of direct measurements of erosion, hydrological processes, and geotechnical stability.
However, after examining the revised manuscript in detail, I do not consider all of the major scientific concerns resolved. In particular, the revised statistical analysis introduces a more serious issue that was not adequately addressed in the previous version. The main concern is the treatment of individual vegetation plots as independent experimental observations when the restoration treatment was applied at the landslide or slope level. This issue affects the interpretation of the Mann-Whitney tests and potentially the PERMANOVA, CAP, and other multivariate analyses. Therefore, although the manuscript has improved considerably, I still recommend **Major Revision**.
The following comments should be addressed carefully.

Major Issues:

1. The revised statistical design appears to suffer from pseudoreplication:

This is now the most important statistical issue in the manuscript.
The authors state that five landslide scars were restored and that three vegetation plots were sampled within each restored landslide. They also sampled three reference slopes, with three plots per reference slope. Therefore, the study contains 5 restored slopes and 3 reference slopes, but 24 vegetation plots. The revised Methods state that differences were assessed at the plot level with n = 24.
The problem is that the restoration treatment was not independently assigned to 15 separate plots. The intervention was applied to five landslide scars. The three plots within each restored landslide are subsamples of the same restored site. Similarly, the three plots within each reference slope are subsamples of the same reference site.
Therefore, the true number of independent experimental units is much closer to eight sites than to 24 independent observations.
This distinction is critical. Treating all 24 plots as independent observations can artificially increase the degrees of freedom. It can also produce artificially small p-values. This is a classical pseudoreplication problem.
For example, the reported Mann-Whitney result for exotic species richness is based on 15 restored plots versus 9 control plots. However, the treatment was actually represented by five restored slopes versus three reference slopes. The reported $p = 0.003$ may therefore give a stronger impression of statistical evidence than is justified by the study design.
The same concern applies to the PERMANOVA. The authors report $F = 2.75$, $R^2 = 0.11$, and $p = 0.012$. However, if the permutation procedure treated all 24 plots as freely exchangeable, the test does not respect the hierarchical structure of the data.
The authors should therefore completely reassess the statistical framework.
At minimum, the authors should:
-- Clearly identify the experimental unit and the observational unit.
-- Treat landslide or reference slope as the independent sampling unit for treatment comparisons.
-- Account for plot nesting within slope.
-- For univariate variables, consider an appropriate hierarchical model, such as a linear mixed model or generalized mixed model where appropriate, with treatment as a fixed effect and slope/site as a random effect. If the very small number of sites makes a conventional random-effect model unreliable, the authors should instead use an analysis that explicitly respects the eight independent sites and clearly acknowledge the resulting low statistical power.
-- For community composition, use restricted permutations or another permutation structure that accounts for plots nested within slopes.
-- Clearly explain the permutation strata and the exact statistical implementation in R.
-- Recalculate all p-values and effect estimates after correcting the design.
This is not a minor statistical refinement. It directly affects the main inferential claims of the manuscript.
If the corrected analysis produces weaker or non-significant results, the manuscript should report those results honestly. The authors should not retain the current significance claims merely because the revised analysis already produced statistically significant results.

2. The study does not establish that the restored and reference slopes are comparable:
The revised manuscript states that reference slopes were selected within the same protected area and under comparable environmental conditions, including elevation, climate, and surrounding vegetation.
This is an improvement, but it does not fully resolve my previous concern.
The authors still do not provide quantitative information demonstrating comparability of the

restored and reference slopes.
The five restored slopes were not even identical restoration units. D1-D3 were shallow failures, whereas D4-D5 involved deeper soil displacement and required slope regrading using heavy machinery. This means that the restored sites may differ substantially in geomorphology, substrate, slope geometry, soil depth, disturbance severity, and engineering treatment.
The reference slopes are also described as representing a gradient from mixed native-invasive communities to predominantly native vegetation. This creates another concern. A reference group with substantial ecological heterogeneity may not represent a single reference condition.
The authors should therefore provide a site-level table containing, at minimum, for D1-D5 and C1-C3:
-- slope angle
-- elevation
-- aspect
-- approximate slope area
-- landslide type
-- estimated soil depth or substrate characteristics, where available
-- geological or volcanic substrate
-- disturbance severity
-- surrounding vegetation
-- hydrological setting
-- major restoration structures present
-- whether slope reprofiling occurred
-- any available pre-restoration site information
If some variables were not measured, this should be stated explicitly.
The authors should also explain how the reference slopes were selected. Were they selected before or after observing the vegetation outcome? Were they selected based on accessibility? Were they selected because their vegetation already appeared similar to the desired restoration state?
This is important because selection of reference slopes can strongly affect the apparent magnitude of restoration success.
The authors should also consider whether the reference slopes should be treated as a range of ecological conditions rather than as a single control group.

3. The treatment itself is heterogeneous, but the analysis treats restoration as one uniform intervention:
The revised manuscript correctly states that the restoration involved several measures. These included live crib walls, living grids, palisades, erosion-control barriers, bioswales, slope regrading, IAS removal, and hydroseeding.
However, this creates an important methodological problem.
The manuscript evaluates the outcome as if there were one treatment called NbS restoration. In reality, the five restored landslides may have received different combinations or intensities of interventions.
D4 and D5 were regraded using heavy machinery. D1-D3 were not described as receiving this treatment. The manuscript also does not provide a site-by-site matrix showing which bioengineering measures were installed at each slope.
Therefore, any difference between restored and reference plots cannot be attributed specifically to hydroseeding. It cannot even necessarily be attributed equally to all NbS measures.
The authors should provide a clear intervention matrix for D1-D5. The matrix should identify which

interventions were used at each site and, where possible, their extent or intensity.
The Discussion should then use the term "integrated restoration intervention" rather than implying that one standardized NbS treatment was experimentally tested.
This point is particularly important because the manuscript's title and conclusions may still encourage readers to interpret the study as an evaluation of NbS effectiveness in a general sense.
The current design is better described as an observational evaluation of vegetation outcomes following heterogeneous restoration interventions.

4. The revised statistical analysis is still incomplete despite the addition of several statistical methods:
The manuscript now lists Mann-Whitney tests, NMDS, PERMANOVA, PERMDISP, CAP, SIMPER, and IndVal.
Adding many statistical procedures does not automatically make the statistical framework rigorous.
The manuscript needs to explain why each method was used and what scientific question each method addresses.
For the Mann-Whitney analyses, the manuscript should report the exact variables tested, the direction of the effect, effect-size confidence intervals where possible, and whether p-values were adjusted for multiple comparisons.
Several related response variables were tested. These include native richness, exotic richness, native cover, exotic cover, proportional native contribution, and proportional exotic contribution.
The manuscript reports several p-values.
This creates a multiple-testing problem.
If multiple hypotheses are tested independently at $\alpha = 0.05$, the probability of obtaining at least one apparently significant result increases.
The authors should therefore state whether a multiple-comparison correction was applied. If not, they should justify why not. A suitable false-discovery-rate or other correction may be considered, depending on the predefined hypothesis structure.
The manuscript should also provide confidence intervals for the main effect estimates.
The current use of "conventional thresholds" for rank-biserial correlation is not sufficiently precise.
The exact classification scheme should be cited and reported.

5. The PERMANOVA result should not be interpreted as strong evidence of restoration effectiveness:
The PERMANOVA result is statistically significant at $p = 0.012$, but the reported R^2 is only 0.11.
This means that treatment status explains approximately 11% of the variation in the community dissimilarity matrix under the current model.
This is not necessarily a weak ecological result. Community composition is naturally affected by many environmental variables. However, the result should not be described as if treatment explains most of the community differences.
The authors should explicitly interpret the R^2 value.
They should also report the number of observations used, the exact distance calculation, the transformation of the community matrix, and whether abundance, cover, or another measure was used.
The manuscript states that Bray-Curtis dissimilarity was used, but it does not sufficiently explain the preprocessing of the species matrix.
The authors should clarify:
-- Whether raw percentage cover was used.

-- Whether the species matrix was transformed.
-- Whether rare species were retained.
-- Whether zero-only species were removed.
-- Whether standardization was performed.
-- Whether the analysis used presence-absence or abundance/cover information.
-- How unidentified taxa such as *Sphagnum* sp., *Poa* sp., and *Erigeron* sp. were treated.
Most importantly, the PERMANOVA should be rerun using a permutation structure that respects the nested sampling design.

6. PERMDISP does not solve the pseudoreplication problem:
The authors state that PERMDISP was used and that dispersion did not differ significantly between groups, with p = 0.517. They then interpret this as evidence that the PERMANOVA result was not driven by unequal within-group variability.
This interpretation is incomplete.
PERMDISP can help evaluate whether differences in multivariate dispersion contribute to a PERMANOVA result. However, it does not correct for pseudoreplication.
The primary issue is still the dependence of plots within slopes.
The authors should therefore avoid presenting the PERMDISP result as if it validates the entire PERMANOVA design.
The revised statistical section should explicitly distinguish between:

1. heterogeneity of multivariate dispersion, and
2. independence of observations.

These are different statistical issues.

7. The NMDS and CAP analyses need more complete reporting:
The NMDS stress value is 0.175. The figure shows partial separation between restored and control plots.
The authors should provide more information about the NMDS analysis.
Please report:
-- number of dimensions
-- number of random starts
-- distance metric
-- transformation applied before calculating Bray-Curtis distance
-- convergence information
-- final stress
-- whether the plotted ellipses represent confidence intervals, standard errors, standard deviations, or another measure
The figure currently gives a visual impression of separation, but visual separation should not be interpreted as strong treatment discrimination by itself.
The CAP analysis also requires greater methodological transparency.
The manuscript reports p = 0.014 but does not provide sufficient information about the CAP model, number of axes retained, proportion of constrained variation, or classification performance.
The authors should report the relevant CAP statistics and explain why CAP was necessary after NMDS and PERMANOVA.
At present, the manuscript appears to use several overlapping multivariate methods without clearly establishing the additional scientific information obtained from each method.

8. SIMPER and Indicator Species Analysis are reported without sufficient numerical evidence:
The manuscript states that SIMPER identified a small group of native species as principal contributors to the differences and that IndVal identified five significant indicator species associated with control plots.
However, the actual numerical outputs are not presented.
This is insufficient for a rigorous scientific report.
For SIMPER, the authors should provide at least the principal contributing taxa, their average contribution, cumulative contribution, and, where relevant, within-group and between-group measures.
For IndVal, the authors should provide:
-- indicator value
-- statistical significance
-- group association
-- permutation procedure
-- number of permutations
-- multiple-testing adjustment
-- exact list of significant species
The statement that "five significant indicator species" were identified is not enough to reproduce the analysis.
The authors should also be cautious with SIMPER. SIMPER is useful for describing species contributions, but it should not be treated as a formal test of ecological importance.

9. The hydroseeding analysis still contains conceptual and mathematical ambiguity:
The hydroseeding section has improved, but the calculation of germination or establishment remains insufficiently transparent.
The authors state that established individuals were compared with the estimated number of seeds applied per square meter, and that germination rate was calculated as the proportion of established individuals relative to estimated seed density.
This is not necessarily equivalent to germination rate.
The manuscript appears to measure established individuals one year after application. This is an establishment measure unless germination was directly observed.
The distinction matters.
A seed may germinate and subsequently die before the one-year survey. Conversely, one individual could represent a seedling that survived establishment. Therefore, "number of established individuals divided by estimated seeds applied" is better described as an establishment proportion or apparent establishment rate unless the authors have direct germination observations.
The authors should revise the terminology.
More importantly, the manuscript does not explain how the number of seeds applied was estimated from seed mass.
The seed mixture is reported in kilograms per 100 m^2, but seed number per unit mass is not given.
The authors should provide:
-- seed mass applied per species
-- estimated number of seeds per unit mass
-- estimated number of seeds per square metre
-- source of the seed-count estimates

-- method used to count or estimate established individuals
-- whether the six plots were six plots in total or six plots per restored landslide
This last point is particularly important. The phrase "using six randomly positioned 1 × 1 m plots distributed across the restored landslides" is ambiguous.
If there were six plots in total, the sample size is extremely small for species-specific establishment estimates across five restored slopes. If there were six plots per landslide, the Methods should state this explicitly.

10. There is a clear taxonomic inconsistency that must be corrected:
The hydroseeding mixture lists *Festuca francoi*.
However, the Results state that *Festuca petraceae* had a very low germination rate.
This appears to be a taxonomic inconsistency or typographical error.
The authors must verify the identity of this species throughout the manuscript, figures, raw dataset, and statistical analysis.
Figure 3 also appears to contain the label "Festuca petraceae", while the Methods identify *Festuca francoi*.
This is not a cosmetic problem. Species identity is fundamental to the interpretation of the hydroseeding experiment.
The authors should check all scientific names against the original seed mixture records and the vegetation dataset.
They should also use a consistent taxonomic authority or reference.

11. The abstract contains a quantitative claim that is not adequately supported in the Results:
The abstract states that hydroseeding species accounted for 82.5% of total germination.
However, the main Results section does not clearly show how this 82.5% value was calculated.
The Results report species-specific values such as 0.037 and 0.017, but the calculation leading to 82.5% is not presented.
The authors should provide the underlying calculation.
The manuscript should also clarify what "82.5% of total germination" means.
Does it mean that 82.5% of all established individuals belonged to hydroseeded species?
Does it mean 82.5% of the expected seed population germinated?
Does it mean 82.5% of the observed seedlings were from the hydroseeding mixture?
These are very different quantities.
The abstract should only retain the statement after the calculation is explicitly defined and reproducible.

12. The claim that hydroseeded species remained important after ten years needs more careful interpretation:
The manuscript states that *Leontodon rigens* had a mean abundance of 187 individuals m^{-2} and *Festuca francoi* had 63.5 individuals m^{-2} after ten years.
These values require clarification.
First, the unit formatting should be corrected.
Second, the authors should explain how individual plants were counted when species may form clumps, tufts, or vegetative structures.
Third, the manuscript should clarify whether these values represent individuals per square metre calculated from the sampled 1 × 1 m plots.
Fourth, the manuscript should explain whether "abundance" refers to individual counts or

percentage cover.
The distinction is important because the study otherwise emphasizes percentage cover as the principal vegetation measure.

13. The manuscript still cannot distinguish restoration effects from natural succession:
The authors have improved the Discussion substantially on this issue. They now explicitly state that long-term recovery resulted from active restoration and natural ecological succession. However, the study design still cannot estimate the relative contribution of these two processes.
The restored sites received several interventions. The sites were then left to develop for approximately ten years. There was no untreated landslide trajectory monitored over the same period. There was also no experimental comparison between hydroseeded and non-hydroseeded portions of the restored sites.
Therefore, the manuscript can demonstrate an association between restoration history and the vegetation state observed in 2024. It cannot estimate how much of that vegetation state was caused by hydroseeding, engineering structures, maintenance, natural succession, propagule dispersal, or site-specific environmental conditions.
The authors should make this distinction explicit.
The phrase "combined effects" may still imply causal attribution. A safer formulation would be that the observed vegetation pattern is consistent with the combined influence of active restoration and natural colonization, but their relative contributions cannot be quantified from the present design.

14. The interpretation of restoration success should be linked to explicit ecological targets:
The authors state that restoration success should primarily be evaluated through recovery of characteristic native habitats and reduction of invasive alien species rather than through species richness alone.
This is a reasonable conceptual direction.
However, the manuscript does not define a measurable target reference condition.
If restoration success means recovery of characteristic native habitat, then the authors should specify what characteristics define the target habitat.
For example, the authors could identify the expected native vegetation assemblage, dominant species, native cover range, invasive species threshold, or other predefined ecological benchmarks.
At present, the reference slopes are heterogeneous. Therefore, it is difficult to determine whether the restored slopes are approaching a specific target ecosystem or simply differ from the selected controls.
The manuscript should distinguish between:
-- restoration success
-- vegetation recovery
-- suppression of exotic species
-- convergence toward a reference ecosystem
-- divergence from disturbed conditions.
These are not equivalent concepts.

15. The absence of baseline data remains a fundamental limitation and should affect the wording of the title and conclusions:
The authors now acknowledge that quantitative pre-restoration vegetation data were unavailable. This is appropriate.

However, the title still uses the phrase "ten years of vegetation recovery."
Strictly speaking, the study contains a ten-year post-restoration assessment. It does not contain a ten-year time series of vegetation recovery.
There are first-year hydroseeding observations and a 2024 vegetation survey. There are no quantitative annual measurements demonstrating a trajectory from 2015 to 2024.
Therefore, the authors should consider whether "ten years of vegetation recovery" implies a longitudinal dataset that does not actually exist.
A title such as "Ten-year vegetation outcomes following Nature-based restoration of landslide scars in the Azores" would be methodologically more precise.
The current title is not necessarily unacceptable, but the authors should carefully consider whether it overstates the temporal design.

16. The manuscript should separate evidence of vegetation persistence from evidence of slope stabilization:
The authors have moderated the stabilization language, which is an important improvement.
However, the Discussion still states that the persistence of vegetation and functionality of the structures "indicate successful long-term establishment of the restoration interventions."
This statement is reasonable if it refers to vegetation establishment.
However, the manuscript should avoid allowing this statement to be interpreted as evidence of engineering stabilization.
No displacement measurements, factor-of-safety analysis, soil shear strength measurements, root reinforcement measurements, pore-water pressure measurements, erosion measurements, or rainfall-trigger analysis are reported.
The absence of new landslides over ten years is also not equivalent to measured slope stability.
The authors should therefore use carefully restricted language such as "no additional landslide events were observed during the monitoring period" rather than "the intervention stabilized the slopes."
This distinction should be applied consistently in the Abstract, Introduction, Results, Discussion, Conclusion, figure captions, and keywords.

17. The ecological connectivity and habitat quality claims remain too strong:
The Discussion states that restoration may contribute to improved habitat quality and ecological connectivity.
The use of "may contribute" is more cautious than the previous version.
Nevertheless, the manuscript still presents connectivity and habitat quality as important implications of the observed vegetation results.
No connectivity analysis was conducted.
No landscape metric was calculated.
No habitat suitability model was used.
No bird abundance, bird occupancy, food availability, or movement data were collected.
The authors should therefore distinguish between measured vegetation outcomes and ecological implications.
The manuscript can state that increased native vegetation cover may have implications for habitat quality. It should not state that habitat quality or ecological connectivity was demonstrated.

18. The data availability statement requires stronger reproducibility assurance:
The manuscript states that the datasets generated or analyzed are available in Zenodo.
This is positive.

However, the authors should ensure that the repository actually contains the complete data required to reproduce every reported analysis.
At minimum, the repository should contain the plot-level species matrix and metadata identifying:
-- plot ID
-- slope ID
-- treatment
-- restored or reference status
-- species name
-- percentage cover or abundance
-- native/exotic classification
-- sampling year
-- plot location or site identifier
-- all variables used in the statistical analyses.
The hydroseeding dataset should also include the seed application data and first-year establishment data used to generate Figure 3 and the 82.5% statement.
The exact R scripts used for the Mann-Whitney tests, PERMANOVA, NMDS, CAP, SIMPER, and IndVal analyses should also be deposited if possible.
The current data statement establishes that a dataset exists, but complete reproducibility requires the data structure and analysis workflow to be sufficiently transparent.

19. The manuscript should not equate lower exotic richness with successful ecological restoration without considering possible differences in initial conditions:
The restored plots had significantly lower exotic richness and exotic cover.
This is an important result.
However, the absence of pre-restoration data means that the authors cannot determine whether restored sites originally had greater exotic pressure than reference sites, lower exotic pressure, or similar exotic pressure.
The initial removal of invasive alien species was also part of the restoration process. The manuscript states that mechanical and chemical IAS control occurred before restoration.
Therefore, lower exotic cover after ten years could result from several mechanisms.
It could result from the initial IAS removal.
It could result from the physical engineering structures.
It could result from hydroseeding.
It could result from maintenance during the first three years.
It could result from natural succession.
It could also reflect inherent differences between sites.
The authors should therefore avoid attributing the lower exotic abundance specifically to hydroseeding or to any single NbS component.

20. The three-year maintenance intervention is a potential confounding factor and should be discussed:
The restored areas were maintained quarterly during the first three years to control IAS and support vegetation establishment.
This is a major intervention.
The manuscript should describe the maintenance protocol in more detail.
How often was each site visited?
What invasive species were removed?
What chemical treatments were used?

Were herbicides used?
Were the same maintenance activities applied equally across all five restored sites?
Were reference sites maintained?
If the reference sites did not receive equivalent management, then the comparison is not simply "restored versus non-restored." It is a comparison between a multi-component restoration and management intervention versus reference slopes.
This should be explicitly acknowledged.

21. The vegetation survey protocol is still not sufficiently standardized:
The manuscript states that vegetation cover was visually estimated for all vascular plant and bryophyte species.
The authors should describe the visual estimation method.
Please specify whether:
-- the same observer surveyed all plots
-- multiple observers were involved
-- observers were calibrated
-- a percentage-cover scale was used
-- cover was estimated continuously or categorically
-- overlapping vegetation layers were allowed
-- total cover was capped at 100%
-- bryophyte cover was estimated separately
-- bare ground and litter were recorded.
Observer-based percentage cover can introduce substantial measurement error.
This is especially important when the sample size is small.
If multiple observers were used, observer identity should be recorded, and observer effects should be considered.

22. Species identification and taxonomic resolution need clarification:
Several taxa are reported only to genus level, including *Sphagnum* sp., *Poa* sp., and *Erigeron* sp.
The authors should explain why species-level identification was not possible.
They should also explain whether these unidentified taxa were retained in the multivariate analyses.
This matters because the species matrix is the basis of NMDS, PERMANOVA, CAP, SIMPER, and IndVal.
If genus-level records represent several different species, treating them as single taxa may alter community dissimilarity.
The authors should therefore state the taxonomic resolution used in all analyses.

23. The manuscript should report descriptive statistics more completely:
The current Results provide several p-values and effect sizes. This is an improvement.
However, the reader still needs more information about the underlying distributions.
For each major response variable, the authors should provide:
-- sample size
-- median
-- interquartile range
-- mean where useful
-- standard deviation or another dispersion measure
-- effect estimate

-- confidence interval
-- p-value.
The boxplots in Figures 4 and 5 are useful, but the numerical results should be reported in the text or a concise table.
The authors should also avoid relying on mean native cover alone when the distribution appears heterogeneous.
Figure 4 visibly shows substantial variation among plots, including low values within the restored group.
This variation should be discussed.

24. The authors should explicitly distinguish statistical significance from ecological significance:
The manuscript reports statistically significant differences in exotic richness and cover.
However, statistical significance does not automatically indicate ecological importance.
The rank-biserial effect sizes of 0.62, 0.49, and 0.50 suggest meaningful differences under the reported analysis, but these values should be interpreted in ecological terms.
The authors should explain the practical magnitude of the differences.
For example, how much lower was exotic cover in restored sites?
Was the difference large enough to represent a meaningful change in habitat condition?
Was there a predefined ecological threshold?
This would make the paper stronger.

Minor Issues:

1. Keywords should be checked against the revised manuscript:
The manuscript currently lists "biodiversity, conservation, hydroseed, NbS, Azores."
This appears inconsistent with the authors' response to the previous review, where they stated that "Azores" had been removed and replaced by terms including landslide, ecological restoration, Nature-based Solutions, protected areas, and vegetation recovery.
Therefore, the manuscript and the author response appear inconsistent.
The final keyword list should be corrected and made consistent with the revised manuscript.

2. The abstract should avoid saying that all hydroseeded species remained important if this is not true:
The Results indicate that some hydroseeded species had very low representation after ten years, while other non-hydroseeded species became dominant.
The abstract should accurately distinguish between initial establishment and long-term persistence.

3. The terminology "control" and "reference" should be standardized:
The manuscript uses both "control" and "reference" slopes.
The ecological design is closer to a reference-site comparison than to a randomized controlled experiment.
I recommend consistently using "reference slopes" or "reference plots" unless the authors can justify the term "control."
This would also reduce the risk of implying a stronger experimental design than actually exists.

4. The abbreviation NbS should be defined once and used consistently:
The manuscript uses Nature-based Solutions, NbS, Nature-based restoration, and Nature-Based Solutions.
The terminology should be standardized throughout.
The capitalization of "Nature-based Solutions" should also be consistent.

5. The figure captions should report the correct statistical information:
Figures 4 and 5 show individual points and boxplots.
If inferential statistics are central to the Results, the figures should indicate the relevant statistical comparison or refer clearly to the corresponding Results section.
However, statistical annotations should only be added after the statistical model is corrected for the nested sampling design.

6. Figure 3 requires correction and methodological clarification:
Figure 3 should use the same species names as the Methods.
The apparent *Festuca petraceae* versus *Festuca francoi* discrepancy must be resolved.
The y-axis should also clearly state whether the values represent establishment proportion, apparent germination rate, seedlings per seed, or percentage.
The current presentation of values such as 0.037 plants per seed is not immediately intuitive.

7. Units should be standardized:
The manuscript reports "187 individuals m2" and "63.5 individuals m2."
The unit should be written as individuals m^{-2}.
The same formatting should be used consistently throughout the manuscript.

8. The statement "all species germinated" should be reconsidered:
The study measures established individuals one year after restoration.
Therefore, the statement "all species germinated" may be stronger than the actual observation.
Unless germination itself was directly observed, the authors should use a term such as "all species showed establishment" or another scientifically accurate term.

9. The term "biodiversity" should be used carefully
The study primarily measures species richness, species composition, abundance, and vegetation cover:
It does not measure genetic diversity, functional diversity, or broader ecosystem biodiversity.
Therefore, the authors should avoid using "biodiversity" as a broad umbrella term when the actual response variable is plant community composition.

10. The reference to the Azores Bullfinch should be moderated:
The Discussion connects vegetation recovery with the habitat requirements of the Azores Bullfinch.
This provides useful conservation context.
However, the present study did not measure bullfinch abundance, occupancy, feeding behavior, nesting, or habitat use.
Therefore, the connection should remain a conservation implication rather than a demonstrated biological response.

11. The manuscript should clearly distinguish invasive alien species from all exotic species:
The Results refer to "exotic species," while the Discussion frequently refers to invasive alien species.
These categories are not necessarily identical.
Not every exotic species is invasive.
The authors should define the classification system and explain whether all exotic taxa recorded in the study are invasive alien species or whether the categories are different.
This distinction is especially important because the manuscript uses reduction in exotic richness as evidence of reduced invasion pressure.

12. The conclusion should be more closely aligned with the actual study design:
The conclusion currently states that restoration interventions "promoted" native vegetation dominance and reduced exotic species representation.
Given the observational design and lack of baseline measurements, I recommend using more cautious wording.
The data demonstrate that restored sites currently have greater native cover and lower exotic representation than the selected reference sites.
The data do not demonstrate the magnitude of change caused by restoration.
This distinction should be maintained in the final paragraph.

13. The manuscript should explain the geographic scope of inference:
The study concerns five restored landslides within one protected area on São Miguel Island.
The conclusions should therefore primarily apply to this ecological and geographical context.
Statements referring to "other island ecosystems" or landslide restoration more broadly should be clearly framed as potential transferability rather than demonstrated generality.

14. The revised manuscript should not claim stronger reproducibility than the Methods currently provide:
The authors state that the Methods have been extensively revised to improve reproducibility.
The revision has indeed improved transparency.
However, the statistical methods still require important additional information. In particular, the nesting structure, permutation restrictions, multiple-testing strategy, NMDS settings, CAP settings, SIMPER settings, and IndVal settings are not sufficiently described.
The authors should revise the Methods before describing the analysis as fully reproducible.

15. The use of ChatGPT should remain transparent and limited to the stated role:
The manuscript provides an explicit statement that ChatGPT was used for language editing, restructuring, clarity, and preparation of peer-review responses, and that it was not used to generate data or conduct statistical analyses.
This disclosure is appropriate.
I do not identify an ethical problem from the disclosure itself.
However, because the revised manuscript contains substantial methodological changes, the authors should ensure that all statistical decisions were independently verified by the authors and that the deposited analysis code reproduces the reported results.

Overall Assessment of the Revision:
The revision has clearly improved the manuscript. The authors have responded constructively to

many of the previous concerns. The description of the restoration interventions is substantially better. The manuscript now identifies the different landslide types and describes the major bioengineering measures. The Discussion also does a better job of separating hydroseeding from natural colonization. The authors have also added an explicit limitations discussion, including the absence of baseline data and the lack of direct hydrological and geotechnical measurements. These are meaningful improvements.
However, the revised manuscript has introduced a critical statistical concern by treating 24 plots as independent observations when those plots are nested within only eight slopes. The Methods explicitly state that statistical comparisons were conducted at the plot level with n = 24. This approach does not adequately reflect the experimental structure because treatment was assigned at the slope level.
This issue must be resolved before the statistical conclusions can be considered reliable.
The authors should not simply add another statistical test. They should reassess the entire inferential framework according to the sampling design.
The corrected analysis may produce similar results. It may also produce weaker results. Either outcome is acceptable scientifically. What is important is that the analysis matches the actual experimental unit.
The manuscript also needs clearer documentation of control-site comparability, intervention heterogeneity, hydroseeding calculations, taxonomic consistency, multiple testing, multivariate analysis settings, and the exact data underlying the statistical results.
The manuscript's strongest contribution is the long-term observation of vegetation outcomes following restoration in a protected island ecosystem. That contribution does not require the authors to claim more than the design can support.
The paper would be stronger if it presented itself as a carefully documented long-term observational assessment of vegetation outcomes after a multi-component restoration intervention.
It should not be presented as a controlled experiment demonstrating the causal effectiveness of hydroseeding or NbS in general.
The distinction is important.
The ten-year interval is valuable. The protected-area context is valuable. The combination of native revegetation, bioengineering, and invasive-species management is also valuable. The finding that native cover was high in restored plots and that exotic richness and cover were lower is potentially important. The observation that naturally colonizing taxa became major components of the vegetation is also scientifically interesting.
The paper therefore has scientific potential.
However, the statistical inference must be corrected before the central conclusions can be accepted with confidence.

Recommendation to the Authors:
I recommend **Major Revision**.
I do not recommend rejection because the manuscript contains a potentially useful long-term dataset and the authors have made substantial improvements since the previous version.
However, I also do not consider the manuscript ready for approval in its present form.
The most important requirement is to correct the statistical analysis for the hierarchical sampling design. The authors should treat the restored landslides and reference slopes as the relevant independent site-level units and account properly for the three vegetation plots nested within each site. The PERMANOVA and other multivariate analyses should also respect this structure.

After this correction, the authors should reassess all reported p-values, effect sizes, and conclusions.
The authors should also correct the hydroseeding terminology and calculations, resolve the *Festuca francoi/Festuca petraceae* inconsistency, explain the 82.5% value in the Abstract, provide complete statistical outputs for SIMPER and IndVal, clarify the reference-site selection, describe the heterogeneous restoration interventions at each site, and ensure that the deposited dataset contains all raw data required to reproduce the reported analyses.
Finally, the Discussion should consistently distinguish *observed association* from *causal restoration effect*. The manuscript provides evidence of the vegetation condition of restored sites ten years after intervention and evidence that those sites differ from the selected reference sites. It does not provide a controlled before-after experiment that can isolate the causal contribution of hydroseeding, bioengineering, maintenance, or natural succession.
If these issues are addressed carefully, the manuscript will be substantially stronger, and the long-term ecological observations will be presented in a scientifically defensible way.

Kind Regards,
F. A. Samiul Islam
Bangladesh.
--Recognized by Web of Science Reviewer Recognition in the 99th percentile of verified peer reviewers (Top 1% worldwide) based on peer review activity during the last 12 months.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Environmental Science and Engineering, Earth Science, Water Quality and Pollution Source, Drinking Water Quality, Water Quality Parameters, Surface Water, Ground Water, Geographical Research, Waste-to-Energy, Wastewater Treatment Technologies, Solid Waste Management, Air Pollution, Renewable Energy, Climate Change, Transportation Engineering, Structural Engineering, Civil Engineering, Ocean Engineering, Agricultural Engineering, River Engineering, Soil and Earth Engineering, Science and Technology, Artificial Intelligence (AI), Machine Learning (ML), Air and Wind, Pollution, Carbon Dioxide Removal Technologies, Agriculture, Hydrology, 3R Strategy, Resource Recovery, Green Energy, Clean Energy Systems, Energy Transition, Climate Resilience, Urban Climate Resilience, Environmental Hazards, Geohazards, Nature-Based Solutions, Ecosystem-Based Design, Environmental Policy & Governance, Data Science, Digital Twins, Blockchain, Remote Sensing, Sustainable Development, Sustainable Urban Infrastructure, Circular Economy.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 03 September 2026

https://doi.org/10.21956/openreseurope.26787.r79695

© **2026 Marrone N.** This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Nunzio Marrone
University of Naples Federico II, Napoli, Italy

The article, as revised by the authors, certainly addresses the issues raised by the reviewers more effectively.
In this respect, in the author's opinion, it may be accepted for indexing, as it constitutes a reasonable case study that could form the basis for further research and, consequently, for subsequent articles.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: My research interests include the environment, hydraulics, hydrology, water resource management and infrastructure, water treatment and civil engineering

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 22 July 2026

https://doi.org/10.21956/openreseurope.25469.r77072

© **2026 Marrone N.** This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Nunzio Marrone
University of Naples Federico II, Napoli, Italy

Nature-based engineering measures offer suitable solutions for soil protection, including protection against landslides. In this regard, the article in question is certainly constructive, but there are several considerations that require further examination.
Furthermore, grass planting can be regarded as an NBS measure, given that it enables the restoration of the ecosystem altered by hydrogeological instability.
In the author's view, there are several aspects that are only partially addressed in the article:
1. The type(s) of landslide referred to in the article are not specified: superficial, deep, etc.;

2. It is not specified which other types of nature-based engineering measures were planned for the landslides in question, for which hydroseeding was also envisaged.
3. The article does not specify the ecological indices referred to, nor does it explain the method of estimation or assessment; similarly, the germination indices and establishment efficiency are not explained.
4. The expected reduction in surface erosion itself is not substantiated.
5. It is not specified how hydroseeding is integrated with surface water management.
6. A paragraph should be included on what may be considered the limitations of the study.
7. In the keywords, it might be advisable to remove the word 'Azores' and include the terms 'landslide' or 'hydrogeological instability'.
8. It should be demonstrated that landslide movements are indeed limited by the planting of vegetation, by incorporating into the landslide model a soil cohesion parameter linked to the presence of roots.
Ultimately, although the article's intentions are positive, its structure is not physically grounded. In conclusion, the article under review requires a major revision.
Nunzio Marrone
DICEA, University of Naples 'Federico II' e
CUGRI (University Consortium for Major Risks), University of Naples 'Federico II' and University of Salerno

References
1. Sarwar A, Caramiello C, Pugliese F, Jomaa S, et al.: A framework for selecting Nature-based Solutions: applications and challenges at the catchment scale. *Journal of Environmental Management*. 2025; **394**. Publisher Full Text

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and does the work have academic merit?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
No

If applicable, is the statistical analysis and its interpretation appropriate?
Not applicable

Are all the source data underlying the results available to ensure full reproducibility?
No

Are the conclusions drawn adequately supported by the results?
No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: My research interests include the environment, hydraulics, hydrology, water

resource management and infrastructure, and civil engineering

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 27 Jul 2026

Tarso Costa

We sincerely thank Reviewer 2, Prof. Nunzio Marrone, for the careful evaluation of our manuscript and for the valuable comments and suggestions. We appreciate the reviewer's expertise in Nature-based engineering and ecological restoration, which has helped us improve both the scientific rigor and the clarity of the manuscript. In response to the review, we have substantially revised the manuscript.
We expanded the description of the restoration interventions by providing a detailed account of the Nature-based Solutions and bioengineering techniques implemented, including live crib walls, living grids, palisades, erosion-control barriers, and bioswales, as well as the characteristics of the landslides and the restoration workflow.
The Introduction was strengthened with additional literature on Nature-based Solutions, ecological restoration, and catchment-scale planning, including recent references suggested by the reviewer. The Methods section now provides a more comprehensive description of the vegetation monitoring protocol, hydroseeding assessment, ecological indices, and statistical analyses, ensuring greater transparency and reproducibility.
The analytical framework was also strengthened by incorporating inferential and multivariate analyses performed at the plot level. The Discussion has been revised to provide a more balanced interpretation of the findings and now explicitly acknowledges the limitations of the study. We also moderated statements regarding slope stabilization and ecosystem functioning, recognizing that the present work evaluates long-term vegetation recovery and does not directly quantify geotechnical stability or erosion processes. Consequently, conclusions regarding slope stabilization are presented as observations consistent with the persistence of vegetation cover and the continued functionality of the restoration structures rather than as direct engineering evidence. We believe that these revisions have substantially strengthened the manuscript and addressed the concerns raised by Reviewer 2. Detailed responses to each comment are provided below. We sincerely thank Reviewer 2 again for the constructive suggestions, which have significantly improved the manuscript.

Comment 1: *The type(s) of landslide referred to in the article are not specified: superficial, deep, etc.*
Response: We thank the reviewer for this important observation. The manuscript has been revised to clearly describe the types of landslides included in the study. We now specify that landslides D1–D3 were shallow failures, whereas D4 and D5 involved deeper soil displacement requiring slope regrading with heavy machinery before restoration. This information has been incorporated into the *Nature-based restoration interventions* section.

Comment 2: *It is not specified which other types of nature-based engineering measures were planned for the landslides in question, for which hydroseeding was also envisaged.* **Response:** We

appreciate this suggestion and have substantially expanded the description of the restoration interventions. The revised manuscript now presents hydroseeding as one component of a broader Nature-based restoration strategy that also included live crib walls, living grids, palisades, erosion-control barriers, and bioswales constructed using natural materials. We also incorporated recent literature on the selection and planning of Nature-based Solutions at the catchment scale (Sarwar et al., 2025), providing a stronger conceptual framework for the restoration approach adopted in this study.

Comment 3: *The article does not specify the ecological indices referred to, nor does it explain the method of estimation or assessment; similarly, the germination indices and establishment efficiency are not explained.*
Response: We agree that additional methodological detail was necessary. The Methods section has been extensively revised to clearly describe the vegetation sampling protocol, germination assessment, and calculation of establishment success. We also expanded the description of the ecological analyses and substantially strengthened the statistical framework by incorporating inferential and multivariate analyses, including Mann–Whitney tests, NMDS, PERMANOVA, PERMDISP, Canonical Analysis of Principal Coordinates (CAP), SIMPER, and Indicator Species Analysis (IndVal), ensuring greater reproducibility and statistical robustness.

Comment 4: *The expected reduction in surface erosion itself is not substantiated.*
Response: We agree with the reviewer and have moderated our interpretation throughout the manuscript. Because surface erosion was not directly quantified, we no longer present erosion reduction as a demonstrated outcome. Instead, we report that no additional landslide events were observed during the ten-year monitoring period and that the restoration structures remained functional and fully vegetated, while acknowledging that future studies should directly quantify erosion and hydrological responses.

Comment 5: *It is not specified how hydroseeding is integrated with surface water management.*
Response: We thank the reviewer for raising this point. The manuscript now explains that hydroseeding was implemented together with several Nature-based engineering measures designed to regulate surface runoff, including bioswales, erosion-control barriers, palisades, and live crib walls. These complementary interventions reduced runoff concentration, retained sediments, facilitated vegetation establishment, and promoted ecological recovery, with hydroseeding representing only one component of the integrated restoration strategy.

Comment 6: *A paragraph should be included on what may be considered the limitations of the study.*
Response: We fully agree and have included a dedicated subsection in the Discussion addressing the main limitations of the study. These include the absence of quantitative pre-restoration vegetation data, the relatively small number of restored and reference slopes, the observational nature of the study, and the lack of direct measurements of hydrological processes, erosion rates, and geotechnical slope stability.

Comment 7: *In the keywords, it might be advisable to remove the word 'Azores' and include the terms 'landslide' or 'hydrogeological instability'.*

Response: We appreciate this suggestion and have revised the keywords accordingly. The geographical term "Azores" has been removed and replaced with keywords that better reflect the scientific scope of the study, including *landslide*, *ecological restoration*, *Nature-based Solutions*, *protected areas*, and *vegetation recovery*.

Comment 8: *It should be demonstrated that landslide movements are indeed limited by the planting of vegetation, by incorporating into the landslide model a soil cohesion parameter linked to the presence of roots.*
Response: We appreciate this valuable recommendation and agree that incorporating geotechnical modelling and root cohesion parameters would considerably strengthen the engineering assessment of slope stabilization. However, such analyses were beyond the objectives and scope of the present study, which focused on long-term vegetation recovery following Nature-based restoration. Rather than making unsupported engineering claims, we have revised the manuscript to clearly distinguish ecological outcomes from geotechnical performance and have moderated all statements regarding slope stabilization. We also highlight that future research integrating ecological monitoring with hydrological and geotechnical modelling would provide a more comprehensive evaluation of the effectiveness of Nature-based Solutions for landslide stabilization.

Competing Interests: The authors declare that they have no competing interests.

Reviewer Report 30 June 2026

https://doi.org/10.21956/openreseurope.25469.r76500

© **2026 ISLAM F.** This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

?

F. A. SAMIUL ISLAM
Department of Civil Engineering, Uttara University, Dhaka, Dhaka, Bangladesh

This manuscript presents a ten-year assessment of Nature-based Solutions (NbS) implemented for ecological restoration and slope stabilization following landslides within the Pico da Vara/Ribeira do Guilherme Special Protection Area in the Azores. The study evaluates vegetation recovery through hydroseeding performance, plant community composition, ecological indices, and comparisons with selected control slopes. The topic is timely and relevant because long-term evaluations of NbS remain limited in restoration ecology, particularly within protected forest ecosystems. The decade-long monitoring period represents a notable strength and has the potential to provide meaningful evidence regarding ecological restoration following landslide disturbances. The manuscript is generally well organized and clearly written. However, despite its scientific relevance, the current version contains several methodological, statistical, and interpretative limitations that reduce confidence in the conclusions. Several claims extend beyond the evidence presented, important methodological details remain insufficiently described, and the statistical analyses are largely descriptive rather than inferential. Consequently, substantial

revision is necessary before the manuscript can be considered scientifically robust.

1. Experimental design requires stronger scientific justification:
The overall study design addresses an important restoration question and benefits from long-term ecological monitoring. Nevertheless, the experimental design contains several weaknesses that limit the strength of causal inference. The study evaluates only five restored slopes and compares them with three control slopes, which represents a relatively small sample size for drawing generalized ecological conclusions. More importantly, the manuscript does not adequately explain the criteria used to select the control slopes. Although the authors mention that the controls represent different environmental conditions, there is insufficient evidence demonstrating that they are truly comparable to the restored slopes regarding slope angle, elevation, aspect, geological substrate, soil properties, hydrological conditions, previous disturbance history, and surrounding vegetation. These environmental variables strongly influence vegetation succession and may confound the observed restoration outcomes. The manuscript should therefore provide a much more comprehensive description and justification of control-site selection and explicitly discuss how environmental variability may influence the interpretation of the results.

2. Absence of baseline ecological data substantially limits restoration assessment:
One of the principal scientific limitations of the study is the absence of quantitative pre-restoration ecological data. Restoration success is evaluated exclusively through comparison with reference slopes rather than through documented ecological changes before and after restoration. Consequently, it is impossible to determine the magnitude of ecological improvement, biodiversity recovery, or reduction of invasive species resulting directly from the intervention. Restoration ecology ideally requires baseline measurements to quantify restoration trajectories over time. Without these data, the study demonstrates the current ecological condition of restored slopes rather than providing direct evidence of ecological recovery. This limitation should be explicitly acknowledged and discussed as an important source of uncertainty.

3. Statistical analyses are insufficient to support several major conclusions:
The statistical framework employed in the manuscript relies primarily on descriptive analyses, including ecological diversity indices and Principal Component Analysis. Although these methods are appropriate for describing vegetation characteristics, they do not provide sufficient statistical evidence to support several of the manuscript's major conclusions. No hypothesis testing is presented to determine whether differences between restored and control slopes are statistically significant. Likewise, confidence intervals, effect sizes, and measures of statistical uncertainty are absent. As a result, conclusions regarding successful biodiversity restoration, improved habitat quality, and ecological effectiveness remain largely descriptive. The authors should either strengthen the statistical analyses through appropriate inferential approaches or substantially moderate the conclusions so that they accurately reflect the descriptive nature of the available evidence.

4. The contribution of hydroseeding relative to natural ecological succession remains unclear:
One of the most interesting findings of the study is that only two hydroseeded species remained dominant after ten years, whereas several abundant species established naturally despite not being included in the hydroseeding mixture. This observation suggests that natural ecological succession, propagule dispersal from adjacent habitats, and spontaneous colonization may have

played a major role in vegetation recovery. However, throughout the discussion, the manuscript attributes restoration success primarily to the hydroseeding intervention without critically evaluating the relative contribution of natural successional processes. The authors should provide a more balanced interpretation, acknowledging that the observed vegetation patterns likely resulted from interactions between active restoration measures and natural ecological processes rather than hydroseeding alone.

5. Interpretation of biodiversity indices requires deeper ecological discussion:
The ecological indices reported in the manuscript reveal an interesting but somewhat contradictory pattern. Restored slopes generally exhibit lower species richness and lower Shannon diversity than several control sites, while simultaneously showing greater dominance of native species. The manuscript interprets this pattern as evidence of successful restoration, yet the ecological rationale supporting this interpretation is not sufficiently developed. Since lower diversity is commonly interpreted as ecological simplification, readers may question how reduced diversity represents restoration success. The authors should explain whether the target ecosystem naturally exhibits relatively low diversity with dominance by characteristic native species and clarify how restoration objectives prioritized recovery of native vegetation rather than maximizing overall species richness.

6. Several ecological conclusions extend beyond the available evidence:
The manuscript repeatedly concludes that Nature-based Solutions enhanced biodiversity, improved habitat quality, restored ecological connectivity, and increased ecosystem resilience. While these outcomes are plausible, they were not directly measured within the study. The data primarily describe vegetation composition and plant cover. No direct measurements of ecosystem functioning, habitat connectivity, ecological resilience, runoff regulation, sediment retention, or ecosystem services were performed. Consequently, these broader ecological statements should either be supported by additional evidence or clearly identified as expected ecological implications rather than demonstrated outcomes of the present study.

7. Structural stabilization claims require additional supporting evidence:
The manuscript reports that no additional landslides occurred during the ten-year monitoring period and interprets this observation as evidence that the Nature-based Solutions successfully stabilized the slopes. Although this result is encouraging, the absence of landslides alone cannot conclusively demonstrate structural stabilization because landslide occurrence is influenced by numerous external factors, including rainfall variability, hydrological conditions, soil moisture dynamics, and geological stability. Without quantitative geomorphological measurements or engineering assessments, the conclusion that the interventions directly prevented landslides remains stronger than the presented evidence supports. The authors should therefore moderate these statements and discuss alternative explanations.

8. Methodological description remains insufficient for complete reproducibility:

Although the manuscript provides an overview of the restoration procedures and vegetation surveys, several methodological details necessary for reproducibility remain absent. The manuscript does not adequately describe the vegetation cover estimation procedure, observer calibration, species identification protocols, randomization of sampling locations, treatment of rare species, statistical software, data transformation procedures, or the specific analytical settings used for Principal Component Analysis and ecological index calculations. Providing these

methodological details would substantially improve transparency and allow independent replication of the study.

9. Interpretation of the Principal Component Analysis requires further development:

The Principal Component Analysis is introduced as supporting evidence for similarities among restored and control slopes. However, the interpretation remains superficial. The manuscript does not report the percentage of variance explained by each principal component, the contribution of individual variables, or the ecological gradients represented by the axes. Without this information, readers cannot fully evaluate the biological significance of the observed clustering. The PCA results should therefore be interpreted more comprehensively within an ecological context.

10. The Discussion does not adequately acknowledge study limitations:

The Discussion emphasizes the strengths and practical implications of the restoration project but provides relatively limited consideration of the study's inherent limitations. Important constraints, including the limited sample size, absence of baseline ecological data, observational study design, potential environmental confounding, restricted statistical inference, and limited geographic applicability, should all be discussed explicitly. A balanced discussion of these issues would improve the scientific credibility of the manuscript and help readers appropriately interpret the findings.

11. The literature review could be further strengthened:

Although the manuscript cites several important publications concerning Nature-based Solutions, additional recent literature from restoration ecology and long-term ecological monitoring could strengthen the Introduction and Discussion. Incorporating more recent studies would better position the present work within the rapidly developing Nature-based Solutions literature and allow for a more comprehensive comparison with previous restoration outcomes.

12. Figures and data presentation could be improved:

The figures successfully illustrate the study sites and general vegetation patterns; however, several figures remain primarily descriptive. Including statistical annotations where appropriate, improving figure readability, and presenting additional quantitative information would enhance interpretation. Similarly, Table 1 would be considerably more informative if statistical comparisons between restored and control slopes were included rather than presenting descriptive indices alone.

Overall Recommendation:

This manuscript addresses an important ecological restoration topic and presents valuable long-term monitoring data that have the potential to contribute meaningfully to the growing literature on Nature-based Solutions. The study possesses several strengths, particularly its ten-year monitoring period and its focus on ecological restoration within a protected conservation area. Nevertheless, the current manuscript is weakened by insufficient methodological detail, limited statistical rigor, incomplete discussion of important limitations, and conclusions that occasionally extend beyond the available evidence. These issues reduce confidence in several of the principal

findings but do not diminish the potential scientific value of the dataset itself.

I therefore recommend **Major Revision**. Addressing the methodological, statistical, and interpretative concerns outlined above will substantially improve the scientific robustness, transparency, and overall impact of the manuscript.

Kind Regards,
F. A. Samiul Islam
Bangladesh.

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and does the work have academic merit?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Environmental Science and Engineering, Earth Science, Water Quality and Pollution Source, Drinking Water Quality, Water Quality Parameters, Surface Water, Ground Water, Geographical Research, Waste-to-Energy, Wastewater Treatment Technologies, Solid Waste Management, Air Pollution, Renewable Energy, Climate Change, Transportation Engineering, Structural Engineering, Civil Engineering, Ocean Engineering, Agricultural Engineering, River Engineering, Soil and Earth Engineering, Science and Technology, Artificial Intelligence (AI), Machine Learning (ML), Air and Wind, Pollution, Carbon Dioxide Removal Technologies, Agriculture, Hydrology, 3R Strategy, Resource Recovery, Green Energy, Clean Energy Systems, Energy Transition, Climate Resilience, Urban Climate Resilience, Environmental Hazards, Geohazards, Nature-Based Solutions, Ecosystem-Based Design, Environmental Policy & Governance, Data Science, Digital Twins, Blockchain, Remote Sensing, Sustainable Development,

Sustainable Urban Infrastructure, Circular Economy.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 27 Jul 2026

Tarso Costa

Dear Samiul Islam,

We sincerely thank the reviewer for the thorough, constructive, and insightful evaluation of our manuscript. We greatly appreciate the time and expertise devoted to reviewing our work. The comments have substantially improved the scientific quality, clarity, and robustness of the manuscript. In response to the review, we have extensively revised the manuscript.
The study has been reframed to focus on long-term vegetation recovery following Nature-based restoration of landslide scars rather than primarily on hydroseeding performance.
The Introduction has been expanded with recent literature on Nature-based Solutions, ecological restoration, protected area management, and the natural vegetation of the Azores to better position the study within the current scientific context.
The Methods section has been comprehensively revised to improve transparency and reproducibility. We now provide a detailed description of the restoration interventions, including the types of landslides, the bioengineering techniques implemented, hydroseeding procedures, vegetation sampling design, and the criteria used for selecting reference slopes. The statistical framework has also been substantially strengthened. Rather than relying primarily on descriptive analyses, we now analyse vegetation at the plot level using inferential statistics, including Mann–Whitney tests with effect sizes, Non-metric Multidimensional Scaling (NMDS), PERMANOVA, PERMDISP, Canonical Analysis of Principal Coordinates (CAP), SIMPER, and Indicator Species Analysis (IndVal).
The Results section has been reorganized to clearly separate short-term hydroseeding performance from long-term vegetation recovery. Statistical comparisons between restored and reference plots have been incorporated throughout, and the multivariate analyses provide a more robust assessment of differences in plant community composition. Figures and captions have also been revised to improve clarity and interpretation.
The Discussion has been substantially rewritten to provide a more balanced interpretation of the findings. We now explicitly distinguish the contribution of hydroseeding from that of natural ecological succession, recognizing that long-term vegetation recovery resulted from the interaction between active restoration measures and natural colonization processes.
We have moderated conclusions regarding slope stabilization, ecosystem functioning, and habitat quality to ensure that they remain fully supported by the evidence presented.
Furthermore, we have expanded the discussion of ecological restoration objectives in the Azores, emphasizing that restoration success should primarily be evaluated by the recovery of characteristic native habitats and the reduction of invasive alien species rather than by increases in overall species richness.
Finally, we have included an explicit section discussing the main limitations of the study, including the absence of pre-restoration vegetation data, the relatively small number of

restored slopes, and the lack of direct measurements of hydrological and geotechnical ecosystem services. We have also incorporated several recent references suggested by the reviewer and additional literature relevant to Nature-based Solutions, ecological restoration, island ecology, and conservation planning. We believe that these revisions have substantially strengthened the manuscript and have addressed the concerns raised by the reviewer. We sincerely thank the reviewer again for the valuable comments, which have significantly improved the quality and scientific rigor of our work.

Best Regards,
Tarso Costa

Competing Interests: The authors declare that they have no competing interests.