Post shallow-landslide habitat disturbance and vegetation recovery status in a wet montane wildlife sanctuary in the eastern highlands of Zimbabwe

Abstract

Landslides are a form of slope failure that may lead to dramatic soil and vegetation mass wasting. This study seeks to assess the vegetation recovery status and succession in areas affected by the March 2019 tropical cyclone Idai, which induced shallow landslides in the Eland Sanctuary. Site observations and floristic surveys were performed to elucidate the extent of habitat recovery and the successional process of the plants. Plant diversity was assessed by estimating the Shannon–Wiener index, whereas species richness was computed via Menhinick's index. Our results revealed fifty-eight shallow landslide sites in the southwestern part of the study area in open woodland areas with poor vegetation cover at elevations between 1418 m and 1673 m and slopes ranging from 20–70 degrees. A total of 1.$^{850\ \mathrm{km2}}$ was affected by shallow landslides in loose soils of clay-silt and loam dominated on impervious substrata. Twenty-nine plant species were recorded across the fifty-eight plots sampled. Species include *Pteridium aquilinum, Pinus patula, Helichrysum* spp., *Vernonathura polyanthes, Cyperus iria* and *Acacia mearnsii.* The Shannon (H) index showed medium diversity (Shannon (H) index = 2.474). The species richness (Menhinick index) was 0.5233. The woody plants recorded were mostly from seedlings, although there was no significant difference among the seedlings, bushes and mature trees (Mann–Whitney test at $p = 0.05$, where the p value = 0.2203). There was no significant difference in the number of invasive plants recorded across the sampled plots for *Pinus patula*, *Vernonathura polyanthes* or *Acacia mearnsii* ($H = 4.57$; $DF = 2$; p value = 0.102, $p = 0.05$). Active habitat restoration using native woody species is recommended.

Keywords: Sanctuary Park, Tropical Cyclone Idai, Shallow landslides, Plant succession, Colonizers, Habitat damage, Invasive plants, and Active Habitat Restoration

1. Introduction

Landslides are a form of slope failure event characterized by rapid mass movement of soil and/or rock along a discrete shear surface, leading to dramatic soil and vegetation mass wasting in sloping areas (Walker and Velázquez, 2009). Landslides can result from disturbances in the natural stability of a slope. They can be triggered by intense rainfall episodes (Stern, 1995), earthquakes or volcanic eruptions (Restrepo and Alvarez, 2006), and human land use practices such as infrastructure construction (Sidle and Ochiai, 2006). Climate change has also increased the frequency and scale of heavy rainfall, increasing the risk of shallow landslides due to heavy rainfall (Hirosi Asada and Tomoko Minagawa 2023). When excess water rapidly accumulates in the ground, it increases the water-saturated surface area that triggers mudslides. Shallow land sliding is the most common geomorphic process in mountainous areas of the world (Innes, 1983; Johnson and Rodine, 1984; Blijenberg, 1998). Shallow landslides usually have small to medium dimensions and typically affect the soil mantle and upper regolith, tending to evolve into unconfined debris flows that affect wildlife habitats and vegetation.

Shallow landslides are disturbances that foster the evolution of slope landscapes as part of their self-regulating capacity (Ollauri and Mickovski, 2017). Landslides constitute a major process of land degradation and, in many areas, are responsible for a substantial fraction of the total sediment delivered from a catchment, resulting in displacement of land within a few meters (Gabet and Mudd 2006). The impacts are the creation of habitat gaps in a community or ecosystem. These gaps provide refugia for colonizing plant species that, in turn, supply many other organisms with food or habitat or negatively affect the vegetation status by facilitating invasion (Wunderle et al., 1987).

Intense rainfall-induced shallow landslides caused by climate-induced flooding can have severe consequences, including soil erosion, vegetation loss and habitat loss. The frequency and magnitude of heavy rainfall events are increasing, leading to a rising trend in the occurrence of slope failure. As a result, among these slope failures, shallow landslides are regarded as the most common type of disaster on slopes (Murgia et al 2022, Asada and Minagawa, 2023).

In ecology, landslides are viewed as natural disturbance events of varying frequency and intensity that contribute to the natural evolution of sloped ecosystems (Walker and Shield 2013); however, the effects of shallow landslides on wildlife habitats and vegetation are mostly negative and, in some instances, catastrophic (Schuster and Highland, 2003). Land morphology and topography change greatly, with features such as massive erosion occurring in a habitat due to landslides, for example, after a catastrophic tropical cyclone that occurred on 15 March 2019, affecting parts of the Eastern Highlands Region of Zimbabwe. The damage caused by this tropical cyclone affected the soil, habitat and water conservation. Landslides impact the Earth's natural environment, including effects on forests and grasslands and the habitats of native flora and fauna (Sams, 2022). Changes in soil characteristics in the sliding area can decrease soil organic matter and plant nutrition (Sparling et al., 2003). Shallow landslides increase the openness of the landscape by displacing material enriched with topsoil (Odum 1969) and establishing vegetation downward on the slope at the time of failure (Walker et al. 1996).

Habitat and vegetation damage are major threats to the maintenance of ecological systems in protected areas and forests. Rapid vegetation recovery at shallow landslide sites is important for increasing land stability and retaining wildlife habitats. However, the status of vegetation recovery processes after shallow landslides in the Eland Sanctuary Park is currently unknown. Examining vegetation recovery following shallow landslides can offer valuable insights into improving future wildlife habitats affected by disasters. The quantitative assessment of the response of vegetation following shallow landslides in natural habitats is critical for determining vegetation succession.

Assessments to determine vegetation recovery status and succession in areas affected by shallow landslides have become important sources of information for decision making (Lin, Lin and Chou, 2006). This can improve efforts to restore long-term surface stability through the establishment of relatively stable plant communities (Walker and Velázquez, 2009. Therefore, it is important to evaluate the natural vegetation recovery status and provide basic information on the ecological aspects of the recovering environment after shallow landslides. The following objectives prompted the study: **(i).** To identify areas affected by tropical cyclone idai-induced shallow landslides, **(ii).** To determine the passive plant species recovery status in habitats affected by shallow landslides induced by tropical cyclones and **(iii).** To assess the status of vegetation succession and invasion at sites affected by tropical Cyclone Idai-induced shallow landslides in the Eland Sanctuary Park of Chimanimani, Zimbabwe.

2. Materials and methods

2.1. Location of the study area

The size of the Eland Sanctuary Park is only $^{18\text{ km2,}}$ and it is located in the Eastern Highlands area of Zimbabwe in the Chimanimani district. The vegetation type is a characteristic of montane woodlands and grasslands. The vegetation is sparse on cliffs. The dominant tree species include *Uapaca kirkiana*, *Brachystegia spiciformis, Julbernardia globiflora rauvolfia caffra*, *Schefflera umbllifera* and *Protea spp*. The common grass species are *Hyperhania species*, *Loudetia simplex* and *Themeda trianda*. The Miombo and *Uapaca* woodlands occupy the slope areas in the central parts, whereas montane grasslands are found on higher grounds, mostly on the eastern side of the park.

The topography of the Eland Sanctuary consists of high-relief Mountains with elevations above 1000 m. The climate of the area is generally considered humid tropical to temperate, with temperatures ranging between 18–25°C during summer (November–April) and between 8–15°C in the winter season (May–August). Rainfall ranges between 1200 and 2000 mm per year. The area is prone to tropical cyclones as a result of its location in the Indian Ocean. Since 2000, at least five cyclones have been recorded in the area. Eland Sanctuary Park and other parts of Chimanimani and Chipinge experienced heavy rainfall on the 15th of March, 2023, with precipitation in excess of 250 mm in 24 hrs accompanied by heavy winds of up to 170 km/h, resulting in numerous shallow landslides. Rainfall-induced shallow landslides are characteristic of areas affected by tropical cyclone events because of their geological, geomorphological, and climatic conditions.

2.2. **Sampling approach**

Shallow landslides tend to have a clearly definable morphology, with an overall spoon shape (Schuster and Krizek, 1978), a nearly vertical arc-shaped ‘headwall’ and a less distinct ‘debris tail’ (Whenua 1997). In this study, a ground survey was performed to identify areas affected by landslides after cyclone Idai occurred on March 15, 2019, at the Eland Sanctuary Park recording location points at each site. A conventional method was then used where site visits to affected areas were performed to assess vegetation recovery status via field floristic surveys of vegetation four years after the tropical cyclone idai induced shallow landslides in Eland Sanctuary Park. A random sampling design was implemented to record the vegetation status at each site affected by shallow landslides. A 1-meter buffer zone from each boundary of the area affected by shallow landslides was delimited within each sampling site to avoid edge effects upon sampling. Scars on upper faces were chosen because lower areas can be affected by subsequent deposition of rafted material (Whenua 1997). A 5 m × 5 m sampling plot was randomly placed at each site affected by shallow landslides. The plots were pegged on the ground with four plastic pegs using a 5 m tape measure. Fifty-eight plots were randomly set for vegetation and soil sampling in areas affected by shallow landslides. In each plot, location data, site number, plot size, elevation, aspect, slope angle, land use type, dominant vegetation type, soil type, humus level, cover status, disturbance level, size of area affected and plant species (grass, woody and sedges) were recorded.

The geographical position of each sampling plot was recorded via a Garmin Etrex-10 handheld global positioning system (GPS device). The soil samples were also collected for soil analysis. Soil samples were collected randomly at the top level in the sampling plot. The collected soil samples were placed into a 500 ml transparent bottle and marked with the point coordinates of each site. Soil samples were collected for laboratory analysis to determine the dominant soil types in each plot and the humus status. The slope gradient at each site was measured with a hand inclinometer, and topographic attributes such as aspects and point coordinates were recorded from the GPS device. The plant species in each plot were identified. The identification process was carried out at the family and species levels via plant identification field guides (Field guide to trees of southern Africa (Wyk & Wyk 1997), Identification guide to southern African grasses (Fish et al., 2015), Handbook on weed identification (Naidu, 2012), (Herbaceous plants Gowanus field guide (Gruberg et al, 2020)). Where the plant species cannot be named, pictures of the plant were taken via a camera and uploaded online at "Flora of Tropical Africa" Facebook and a leaf snap phone application for assisting in plant identification by experts.

3. Data analysis

3.1. Size of the study area affected by shallow landslides

To calculate the percentage of wildlife area affected by shallow landslides in the study area, the following formula was derived:

$$\%age\ Area\ Affected = \left(\frac{Total\ Area\ (Shallow\ Landslide)\ (km2)}{Total\ Size\ of\ Study\ Area\ (km2)}\right) x\ 100$$

3.2. Topographic attributes and soil samples

The topographic attributes were used for analysis of their effects on the occurrence of shallow landslides. The soil samples collected during data collection were analyzed via the simple method of Matsa et al. (2023) to determine the soil type and humus level, where a flat-bottomed clear jar was ¾ filled with soil and water. The soil and water are then mixed so that all the soil is broken into individual particles (Krasner and Amy 1995; Schott 2020). The jar was then placed for one minute, which was the deposition time frame for the sand particles. The deposition of silt particles occurs after one hour, and the deposition of clay particles occurs after 24 hours. The humus content remained suspended on top of the water. Lines were drawn on top of each soil type layer and were measured to determine the percentage of each soil type in the plot, of which all percentages summed to 100%. The soil type percentages were then used for analysis via the soil texture triangle designed by Milton Whitney (1911). The soil texture triangle was used to determine the soil type (sand, clay or loam soil) that was most affected by shallow landslides.

3.3. **Plant diversity metric determination and indicator species analysis**

Plant diversity was assessed by estimating the Shannon–Wiener index. The cumulative species richness (*S*) was computed as the cumulative richness encountered over the plots belonging to a given sampling plot. Species richness per unit area (Sa) was calculated via Margalef's index and Menhinick's index, which calculate species richness independently of the sample size collected.

4. Results

4.1. Distribution of sites affected by shallow landslides in relation to vegetation and soil type

Fifty-eight sites were recorded in the southwestern part of the Eland Sanctuary Park, and the affected areas were characterized by open woodlands dominated by miombo and *Uapaca* with poor vegetation cover (**Figure 1**). A total of 1.850 km^2 (10.3%) was affected by shallow landslides in the study area.

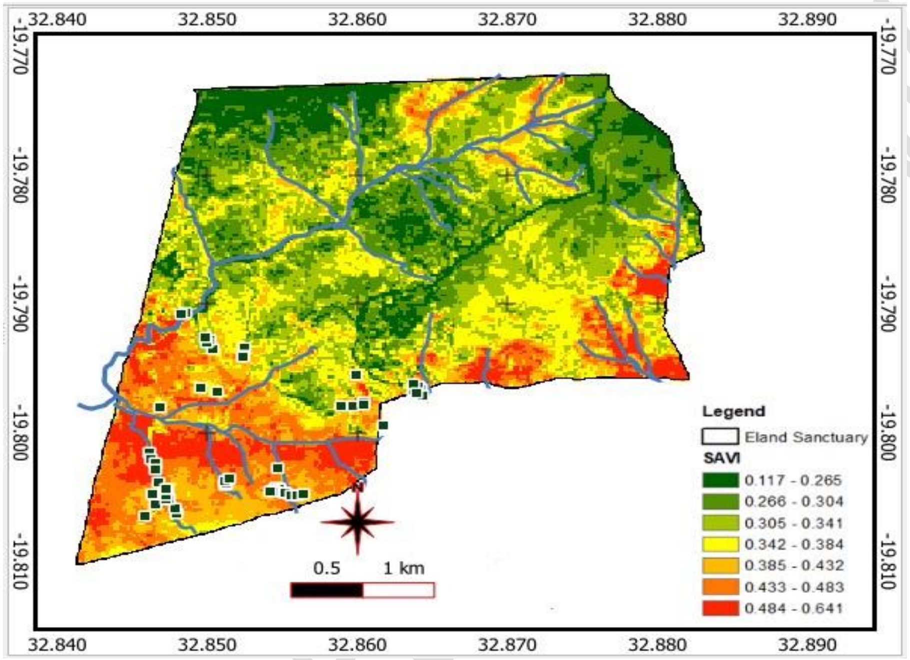

Figure 1: Distribution of landslides (black squares) in relation to the soil-adjusted land cover index in Eland Sanctuary Park

4.2. Vegetation type, elevation, slope and number of slides

The sizes of areas affected by shallow landslides vary between 25 m^2 and 420 m^2, and areas with elevations between 1418 m and 1673 m are characterized by slopes ranging from 20–70 degrees **(Figure 2).** There were seventeen sites (29.3%) recorded in mixed miombo-*uapaca,* nine (15.6%) in Uapaca, eighteen (31%) in miombo, six (10.4%) in mixed woodland, six (10.4%) in *Widdringtonia nodiflora*-dominated habitats, the lowest two (3.4%) and six (10.3%) in the riverine.

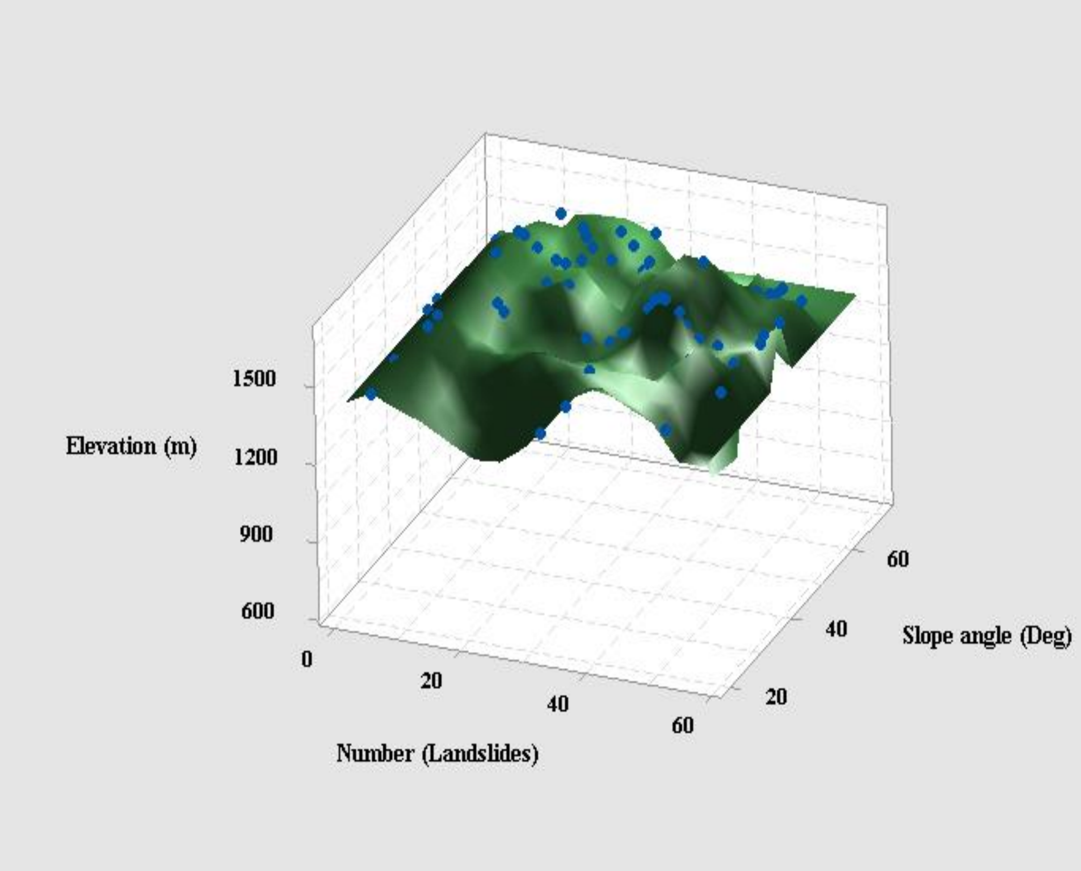

Figure 2: Locations of landslides in relation to elevation (m) and slope angle (deg.) in the study area

Areas that are highly affected by shallow landslides contain shallow and loose soils on impervious substrata. The soils with high clay, clay loam, silt–clay–loam and silt–loam–sized grains were most associated with landslides.

4.3.Species recorded and diversity at affected sites and recovery levels.

Twenty-nine plant species were recorded across the fifty-eight plot samples in seven habitat types. The number of plants recorded by Uapaca kirkiana was the highest (Figure 3).

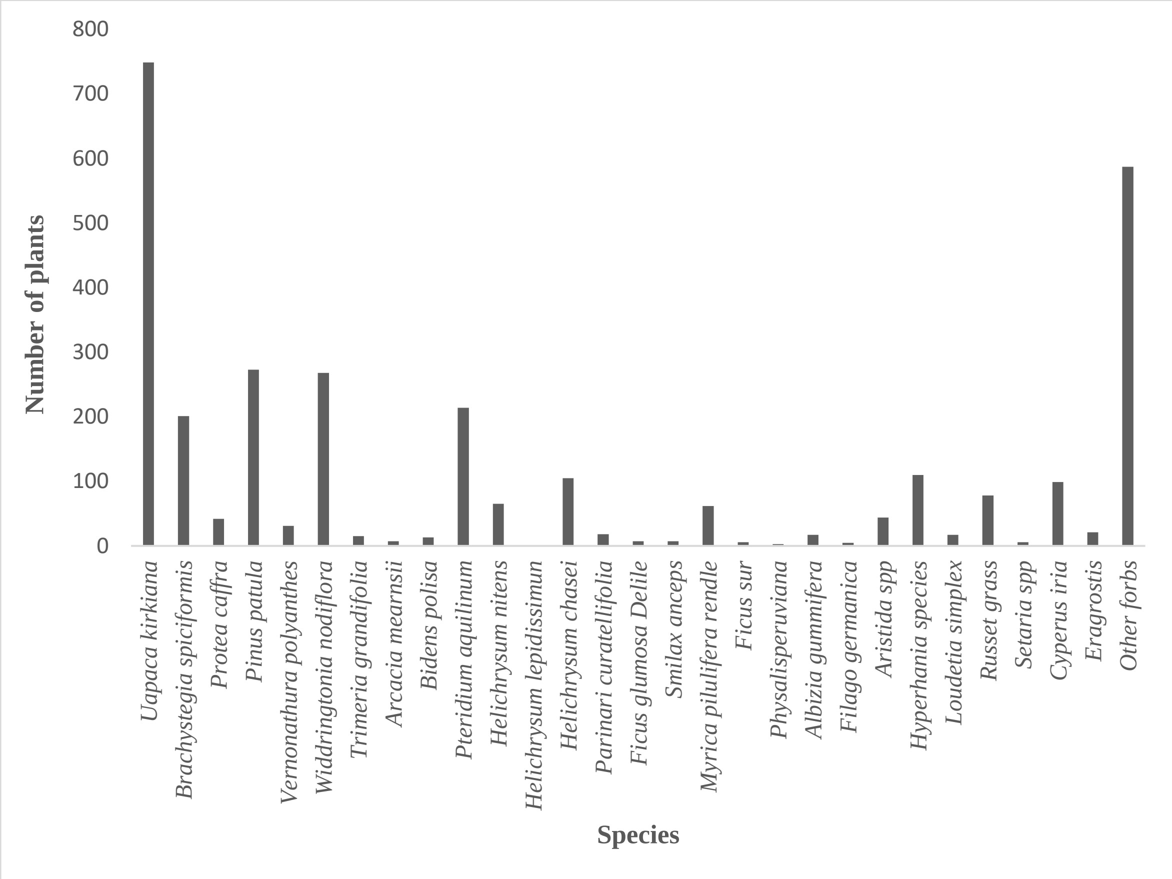

Figure 3: Species recorded in areas affected by shallow landslides.

Diversity analysis performed with Paste 2.14 statistical software at the 0.95% confidence interval *revealed that the Shannon (H)* index was 2.474, indicating medium diversity. The species richness based on the *Menhinick index* was 0.5233, and the *Margalef index* was 3.487.

4.4. Woody plant recruitment status

The woody plants recorded were mostly from seedlings rather than from the coppicing or recovery of mature trees, with the exception of *Trimeria grandifolia* (**Figure 4**). However, the results were not significantly different according to the Mann–Whitney pairwise comparison at p = 0.05, where p (same) was 0.2203.

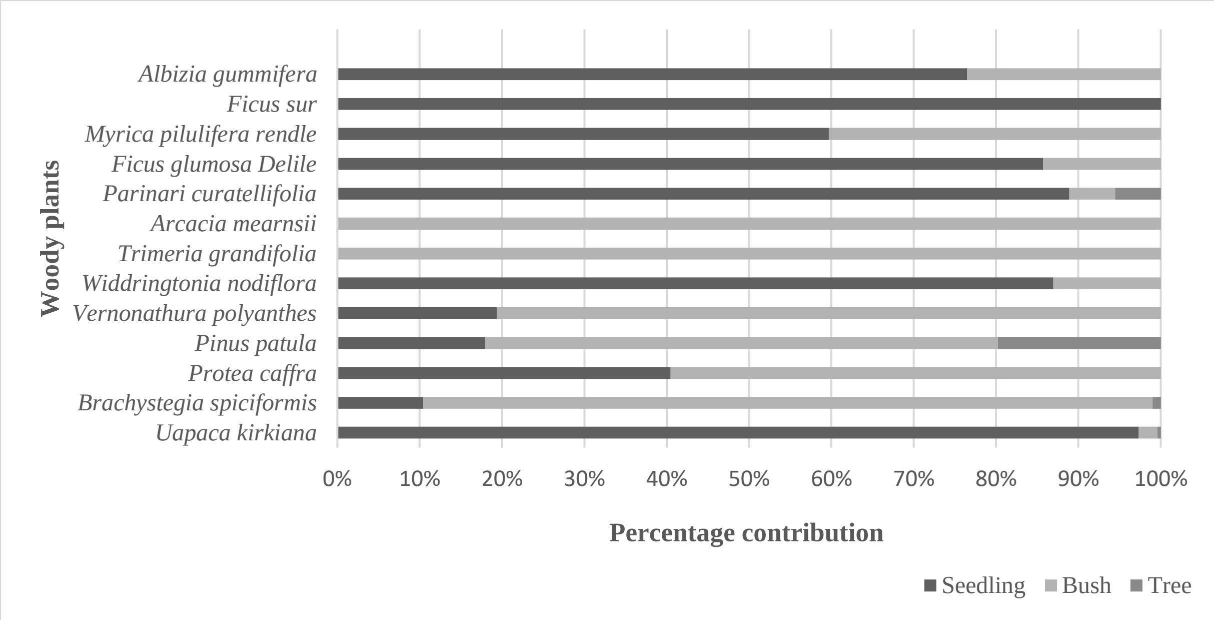

Figure 4: Wood plant species comparison from the sampled plots in different habitats of the study area

4.5. Invasive plant status in areas affected by shallow landslides

The Kruskal–Wallis test was performed to determine if there was a significant difference in the number of new invasive colonizers recorded in the sampled plots (Table 1).

Table 1: Comparison of the number of plants and plots recorded with alien plants

	Number of plants recorded	Number of plots where present
Pinus patula	273	31
Vernonathura polyanthes	31	13
Acacia mearnsii	7	4

The results revealed no significant difference in the number of plants recorded among the three species (H =4.57; DF = 2; p value = 0.102) at $p = 0.05$.

5. Discussion

5.1. Areas and locations affected by shallow landslides in the study area

The southwestern part of the Eland Sanctuary was the area most affected by shallow landslides induced by Cyclone Idai. These affected areas are mostly found in open woodland areas of mixed-miombo-*uapaca*, *uapaca* dominated, miombo dominated and other mixed but sparsely vegetated areas. There are few shallow landslides in areas with high vegetation cover, such as montane grasslands and woodlands. This may be a function of vegetation cover, where thick vegetation holds soil in place while open lands are highly exposed to running water.

Our findings indicate that areas affected mostly by shallow landslides are distributed mainly in steep terrain, including areas at the bottom of gullies and along riverine and stream channels. In these areas, once the soil is saturated, it easily becomes slippery due to reduced friction. The associated soils recorded in these areas are prone to landslides because of their low resistance. Clay and silty-loam soils can easily become saturated and less resistant to movement. When more sediment flows down a river, it can cause flooding, leading to erosion of the surrounding areas. Increased sediment flow along river channels causes a rapid, unstable build-up of material on the riverbank, which results in a slide.

Our findings are also consistent with those of Prancevic et al. (2020), who reported that steeper slopes require smaller hydrological triggers for shallow landslides to occur due to the added downslope pull of gravity, which should result in more frequent landslides and faster erosion. A result of these actions, the affected areas are left exposed to open ground, and further mass movements can occur (**Figure 5**).

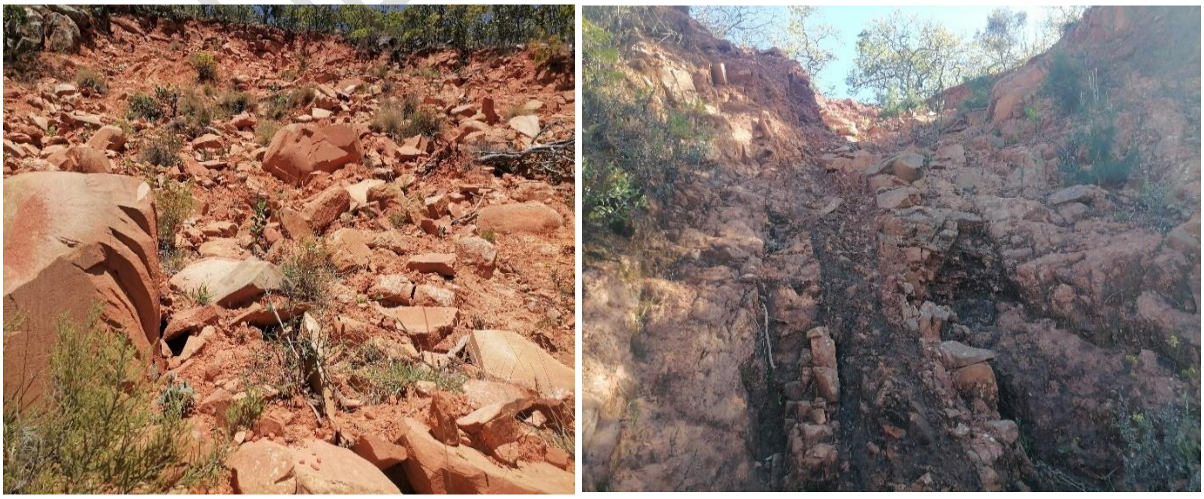

Figure 5: Shallow landslide scars recorded on steep slopes in the study area

5.2. Vegetation Recovery Status

Vegetation recovery in areas affected by shallow landslides was recorded from seedlings, coppicing from roots and from tree branches. Most coppicing and recovery from fallen trees and roots were recorded in *Myrica pilulifera rendle, Protea caffra, Brachystegia spiciformis,* and *Ficus sur*, whereas trees that grow directly from seeds were mostly recorded in *Uapaca kirkiana, Widdringtonia modiflora, Pinus patula* and *Albizia gummifera*. Other nonwoody plants, including *herbaceous* species, grow from seeds and bulbs, and these plants include *Helichrysum nitens, Helichrysum lepidissimun, Helichrysum chasei, Pteridium aquilinum* and *Cyperus iria*. Approximately 87% of the woody plants recorded grew from seeds, and sixty-eight percent of the recorded plants were seedlings.

The findings show that the vegetation recovery process in the study area has a protracted duration, and it is likely to take much time before the affected sites fully recover. There is evidence that the survival of seedlings, especially *Uapaca kirkiana*, is low because several factors, including utilization by herbivores, wilting during the dry season, poor adaptability to environmental conditions and low nutrient levels in the soil, support the growth and survival of seedlings. This is evidence of a poor recruitment rate between seedlings and small bushes. The majority of the seedlings were less than one year old. Four years after a major landslide event, the surveyed sites also recorded low regeneration in the initiation zones and an indication of slower vegetation recovery. Low vegetation recovery can also be attributed to the severity of the landslide disturbance that occurred. Mostly, the topsoil was washed away to pattern rock. Furthermore, unfavorable conditions for vegetation recovery, such as middle to upper elevations, steeper and southwest-facing slopes, and slightly divergent terrain, were widespread in the landslide-affected areas and contributed to delayed vegetation recovery. The cumulative effect of these conditions exacerbates challenges for revegetation, including limited resources, increased erosion risk, and reduced microclimatic suitability.

5.3. Vegetation succession status

The number of first colonizers recorded in these affected areas includes herbaceous and woody plants. The common plants recorded include *Uapaca kirkiana, Protea caffra, Pinus patula, Widdringtonia nodiflora, Helichrysum nitens, Helichrysum lepidissimun, Helichrysum chasei, Parinari curatellifolia, Ficus glumosa Delile, Smilax anceps, Myrica pilulifera rendle, Ficus sur, Physalis peruviana, and Albizia gummifera.* The grass species were *Aristida, Hyperhania, and Loudetia simplex,* while a number of Forbs were also dominant.

Pteridium aquilinum, *Pinus patula*, *Helichrysum* species, *Vernonathura polyanthes, Cyperus iria* and *Acacia mearnsii have been reported to invade disturbed areas as colonizers*. These species are the primary invaders to newly disturbed environments during the processes of primary succession and, in some cases, secondary succession. *Pteridium species* are among the most prominent plant life forms that colonize landslides in tropical locations (Walker and Sharpe, 2010). They have rapid growth rates (Walker and Aplet 1994). According to Walker et al. (2010), *Pteridium* species form monospecific stands on landslides. *Pteridium* and *Helichrysum* species can be present during some or all of the stages of landslide succession. *Widdringtonia nodiflora* was also a good colonizer and promoted good recruitment from seed growth. The plant typically grows among rocks and steep slopes. Grasslands represent one of the most successful groups of plants that can rapidly colonize and dominate landslides for several years following disturbance (Velazquez and Gomez-Sal 2009). Tropical landslides with bare soils can be quickly covered by grasses. Valazquez and Gomez-Sal (2009) reported that grasses, particularly *Hyparrhenia rufa*, were the dominant initial colonists and persisted as dominants throughout the first 4 years of succession on a large landslide in the Nicaraguan dry forest.

Our findings establish that these colonizers reproduce and grow quickly, enabling them to take advantage of resources in barren environments before larger competitors arrive. Through their interactions, pioneer species build a simple initial biological community that gradually gives way to other species. As ecological succession continues, the community advances through one or more intermediate stages to reach a relatively stable mature or climax structure dominated by a small number of prominent species.

5.4. Alien plant invasion status at affected sites

A close look at the disturbance as a result of landslides revealed likely changes in vegetation type over time. New species of invasive plants were recorded in at least 53% of the plots sampled where they were establishing themselves, and the species included *Pinus patula* (273 plants), *Vernonathura polyanthes* (31 plants) and *Acacia mearnsii* (7 plants). These plants are characterized by fast growth and can spread quickly and outcompete herbaceous plants, and after establishment, they can spread to other areas, hence potentially leading to changes in ecosystem structure.

From the surveys, it was observed that invasive plants were outgrowing native plants, with 96% of recorded alien plants at least one meter above the ground, and had established themselves from seedlings, an indication of fast growth and adaptability to affected areas (**Figure 6**). On the other hand, native plants growing from seeds were still less than 30 centimeters in height and were mostly less than one year old.

The establishment of invasive plants in affected areas may facilitate the competitive ability of invasive plants with native plants in more stressful environments. Invasive plant species have several qualities in common, and they adapt to help them colonize harsh sterile environments; they tend to germinate, grow, mature, and reproduce quickly; and they produce large numbers of offspring, either asexually or through wind-dispersed pollen, spores, and seeds. In addition, the seeds and other propagules of many pioneer species are adapted to low-moisture environments, which allows them to survive long periods of dormancy.

Figure 6: Alien invasive plants (Pinus patula and Acacia mearnsii) recorded in areas affected by shallow landslides in the study area

Our findings suggest that invasive plant establishment on shallow landslides can occur in a short time frame. Succession is an imperative ecological concept that can be studied to determine how affected sites respond to a disturbance and thereby motivate restoration techniques. The findings of this study allow for targeted and nuanced monitoring and assessment of vegetation dynamics, enabling effective management and decision making in post landslide affected ecosystems. Therefore, active habitat restoration is recommended where fast-growing trees and shrubs are best suited from local native plants, with a focus on removing invasive plants from areas affected by shallow landslides. Further research is needed to investigate the reciprocal influences of geomorphic processes on vegetation recovery dynamics by simulating nutrient level changes.

6. Conclusions

This study investigated vegetation recovery and succession status after four years of rainfall-induced landslides disturbed by the tropical Cyclone Idai in the Eland Sanctuary Park. Open habitats with sparse vegetation were the most affected. Vegetation recovery is poor and inconsistent, and the affected sites are taking protracted time (four years) without reaching a near-stable state. This may be related to the severity of landslide disturbance, low humus level and lack of restoration work after the occurrence of shallow landslides. Recording nonindigenous plants of *Pinus patula*, *Vernonathura polyanthes* and *Acacia mearnsii* in the affected areas may define plant succession, which influences habitat changes. This study provides insights into the long-term impacts of shallow landslides on vegetation recovery, growth stability and succession. These results successfully address the primary motivation for investigating vegetation recovery and succession and hence suggest that active habitat restoration that aims to improve recolonization by native plants in affected areas while suppressing the growth of invasive plants by alien plants.

Data availability: Data will be provided upon reasonable request.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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