

Evaluating restored ecosystem functions in the rehabilitated watershed in Manolo Fortich, Bukidnon, Philippines using landscape function analysis

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ABSTRACT. Landscape Function Analysis (LFA) was employed in assessing the restoration of ecosystem functions in a degraded watershed along the southern portion of Mt. Kitanglad in Manolo Fortich, Bukidnon, Philippines, rehabilitated using *Calliandra calothyrsus* Meissn. This part of the Mt. Kitanglad Mountain Range is mostly degraded with unproductive grasslands and massive areas planted with monocrop of corn. The LFA indices for stability, infiltration, and nutrient cycling were determined in four seral stages of *Calliandra*: RA1 (1-year-old *Calliandra*), RA4 (4-year-old *Calliandra*), RA6 (6-year-old *Calliandra*), and RA12 (12-year-old *Calliandra*) and were compared with grassland (GL) and adjacent secondary growth forest (SF). Results showed that indices of stability, infiltration, and nutrient cycling were highest in the SF at 84.7, 79.4, and 79.8, respectively. Indices for the RA12 approach that of the SF have values of 84.5, 65.3, and 64.4 for stability, infiltration, and nutrient cycling, respectively. All indices for the different seral stages (RA1, RA4, and RA6) were lower than SF, GL, and RA12. Stability index for the rehabilitated areas was in order RA12>RA4>RA6>RA1. Infiltration and nutrient cycling indices were in order RA12>RA6>RA4>RA1. LFA was a useful tool in utilizing *Calliandra* as a pioneer species in watershed rehabilitation to hasten the biogeochemical functions of rehabilitated sites and approaches the ecosystem functions of the SF with an increase in age compared to when no rehabilitation efforts were conducted as in the GL ecosystem.

Keywords: *Calliandra*, infiltration, landscape function analysis, nutrient cycling, stability

INTRODUCTION

Watersheds in the Philippines provide invaluable ecosystem services such as water supply for domestic and irrigation, biodiversity conservation, hydropower energy, and maintenance of rivers, lakes, wetlands, and coastal ecosystems (Pulhin *et al.*, 2006; Salas, 2008; Lasco *et al.*, 2010; Cruz, 2012). Many of these watersheds are in varying states of degradation, saddled with soil erosion problems, unpredictable streamflow patterns, diminishing groundwater reserves, loss of

biodiversity, declining land productivity, increasing population (Cruz, 2012), and farm expansion and shifting cultivation (GIZ & DENR, 2013). More than 70% of the total land area of the Philippines lies within watersheds which provide irrigation water to about 1.5 M ha of agricultural lands (Lasco *et al.*, 2010), industries, power energy, ecotourism, and domestic values to 17–22 million people. Watersheds also serve as habitats for diverse flora, fauna,

microorganisms, and other lifeforms (Postel & Thompson, 2005; Cremachi *et al.*, 2013; GIZ & DENR, 2013).

With the various services the watershed provides, there is, therefore, the need to properly manage these areas to provide the desired goods and services without adversely affecting water, soil, and water resources (Brooks *et al.*, 1991). Watershed rehabilitation techniques that should be employed can minimize or reduce soil erosion, sedimentation, and surface runoff.

The main strategy of the Philippines for watershed rehabilitation is through government reforestation activities and private commercial tree plantation establishment. Fast-growing species (*Swietenia macrophylla* King, *Acacia mangium* Willd., *Acacia auriculiformis* Benth., *Eucalyptus deglupta* Blume, and *Gmelina arborea* Roxb.) are commonly used as watershed rehabilitation species, whose growth are affected by drought, poor soils, or strong winds (Lasco & Pulhin, 2003; Combalicer *et al.*, 2012; Chechina & Hamann, 2015). In the case of the Philippine government's rehabilitation programs, the objectives are to re-green barren lands, produce timber, enhance watershed services and address upland poverty (Chokkalingam *et al.*, 2006). Cruz *et al.* (2007) broadly classified forest restoration strategies in the Philippines, namely afforestation, reforestation, assisted natural regeneration (ANR), enrichment planting, timber stand improvement (TSI), and agroforestry. Implementing the National Greening Program (NGP) through Executive Order No. 26 in 2011 is a reforestation program. The NGP aims to reduce poverty, promote food security, environmental stability, and biodiversity conservation, and enhance climate change mitigation and adaptation with the Department of Environment and Natural Resources (DENR) as the mandated lead agency. NGP specifically seeks to plant 1.5 B seedlings in 1.5 M ha of public lands nationwide in six years, from 2011 to 2016. NGP's strategies are: 1) social mobilization, 2) harmonization of initiatives, and 3) provision of incentives, monitoring, and database management. NGP's reforestation strategy is directly planting seedlings into the rehabilitation/watershed sites and tapping private organizations (PO) members to plant.

Watersheds, consisting of terrestrial, freshwater, and coastal ecosystems in a land area that drains to a common water source, provide benefits such as water supply and purification, habitat for wildlife, carbon sequestration, climate regulation, and recreation (Postel & Thompson, 2005). The services that watersheds produce sustain agriculture, fisheries, commercial industry, transport, and tourism (Cruz, 2012).

While directly planting trees was the traditional method used to rehabilitate degraded Philippine uplands, the Hineleban Foundation, Inc. (HFI) in Manolo Fortich, Bukidnon, initiated the Associated Pioneer Climax Species (APCS) method. The APCS technique closely mimics the natural succession process wherein a fast-growing pioneer species (*Calliandra calothyrsus* Meissn.) is first planted in grasslands to dominate and eliminate cogon grass (*Imperata cylindrica* L.) and talahib (*Saccharum spontaneum* L.), after which indigenous dipterocarp, oak species, and select commercial species were introduced. APCS has proven effective in rehabilitating degraded areas in Vietnam and Thailand (Van So, 2000).

The fast-growing tree species *C. calothyrsus* was used as a pioneer species in suppressing *I. cylindrica* grasslands in Manolo Fortich, Bukidnon (Binayao *et al.*, 2021). *Calliandra* was also used to reduce fire hazards and facilitate site colonization by a wider range of species by planting desired premium species, such as dipterocarps, to accelerate rehabilitation. *Calliandra* was effective in shading weeds, specifically cogon and talahib, with no allelopathic effect on the planted late-successional species. Additionally, the nitrogen-fixing characteristic of *Calliandra* was observed to be beneficial to the growth of planted late-successional species.

The standard protocol for evaluating rehabilitation programs involves the seedlings/species' survival count (*e.g.*, NGP plantings – DENR 2021). The practice is important, but such an evaluation system misses out on other vital aspects of rehabilitation, particularly the restored ecosystem functions, which are essential in bringing back the lost ecosystem goods and services. The contribution of *Calliandra* in rehabilitating the

degraded areas in the Mt. Kitanglad Range Natural Park (MKRNP) was assessed using the Landscape Function Analysis (LFA). Tongway & Hindley (2004a) referred to LFA as a rapid monitoring tool to assess how a certain landscape works as a biophysical system. LFA uses soil surface indicators to assess the status of a given ecosystem in terms of functionality, *i.e.* the degree to which resources tend to be retained, used, and cycled within the system (Tongway & Hindley, 2004b). The assessment yielded LFA indices for stability, infiltration, and nutrient cycling, which can be used to describe the current functional state of an ecosystem in terms of resistance to erosive forces, infiltration of water into the soil in a rainfall event, and the rate at which nutrients are returned into the soil, respectively. These indices are reliable indicators of restored ecosystem functions important in producing the watershed's ecosystem goods and services. Several studies have employed LFA in assessing landscape function status, *e.g.*, 34 nature reserves and one potential reserve in Australia (Tongway & Hindley, 2004a); gold mine (Summerfield, 2006; Smits, 2008); degraded catchment prior to natural sequence farming (NSF) (Marchiori, 2006); in assessing a catchment recovery from fire and post-fire disturbances (Lane, 2008). Furthermore, the ecosystem function indices of soil stability, nutrition cycling, and infiltration rates were highly related to field values in Kelian Equatorial Mining gold mine (Tongway *et al.*, 2003). In the Philippines, LFA has been field-tested in several mining areas to evaluate the mine rehabilitation progress (DENR & UPLB, 2014; Calalo, 2017).

The study promoted innovations in assessing rehabilitation progress using LFA in portions of Mt. Kitanglad Mountain Range in Manolo Fortich, Bukidnon, Philippines.

METHODOLOGY

Description of the study site

The study was conducted in Barangay Kalugmanan, Manolo Fortich, Bukidnon and located at N 08°12' 40.0", E 124°52' 27.0" and N 08°12' 51.5", E 124° 52' 33.7" (Figure 1). The climate falls under Type III of the Modified

Corovna's Classification, characterized by a short dry season lasting only from one to three months with no pronounced maximum rain period. The area is virtually cloud-covered throughout the year, with temperatures ranging from 22.7°C during January to 24.6°C in June. Relative humidity varies from 71% in May and 86% in September (https://en.wikipedia.org/wiki/Kitanglad_Mountain_Range). The study site is part of the MKRNP in Bukidnon and encompasses 47,270 ha and includes parts of the municipalities of Baungon, Talakag, Lantapan, Impasugong, Sumilao, Libona, and Manolo Fortich and the City of Malaybalay, sharing boundaries at the summit (Makapukaw & Mirasol, 2004).

The location, compass reading, position in the landscape, and existing land uses are shown in Table 1. The first reforestation site of the HFI using *Calliandra*, established in 2002, represented the 12-year-old *Calliandra* stand and is denoted as RA12. Other sites were those *Calliandra* plots established in 2008 (6-year-old, RA6), 2010 (4-year-old, RA4), and 2013 (1-year-old, RA1). The performances of the different ages of *Calliandra* were compared with an adjacent grassland (GL) located on the upper slopes to the crest of a hill and a secondary growth forest (SF) along a stream channel. Table 2 presents the schedule of activities for using *Calliandra* in watershed rehabilitation.

Establishment of transects and monitoring plots

Transect lines of 15 m were established in each rehabilitation site, GL and SF, directly downslope. Five transect lines were established (Figure 2) for soil surface assessment (SSA). In flat areas, the transect direction was not so critical; however, transect lines followed the slope direction in sloping areas. Measurement of continuous patch/inter-patch length and width (for patches only) were recorded. Patches are vegetation or obstruction that tend to accumulate resources by restricting the downslope flow of water, topsoil, and other organic matter. Patches can be plants like trees and grasses, branches, and stones. Inter-patches are areas where resources flow more freely. Inter-patches are bare soil that allows the escape of resources.

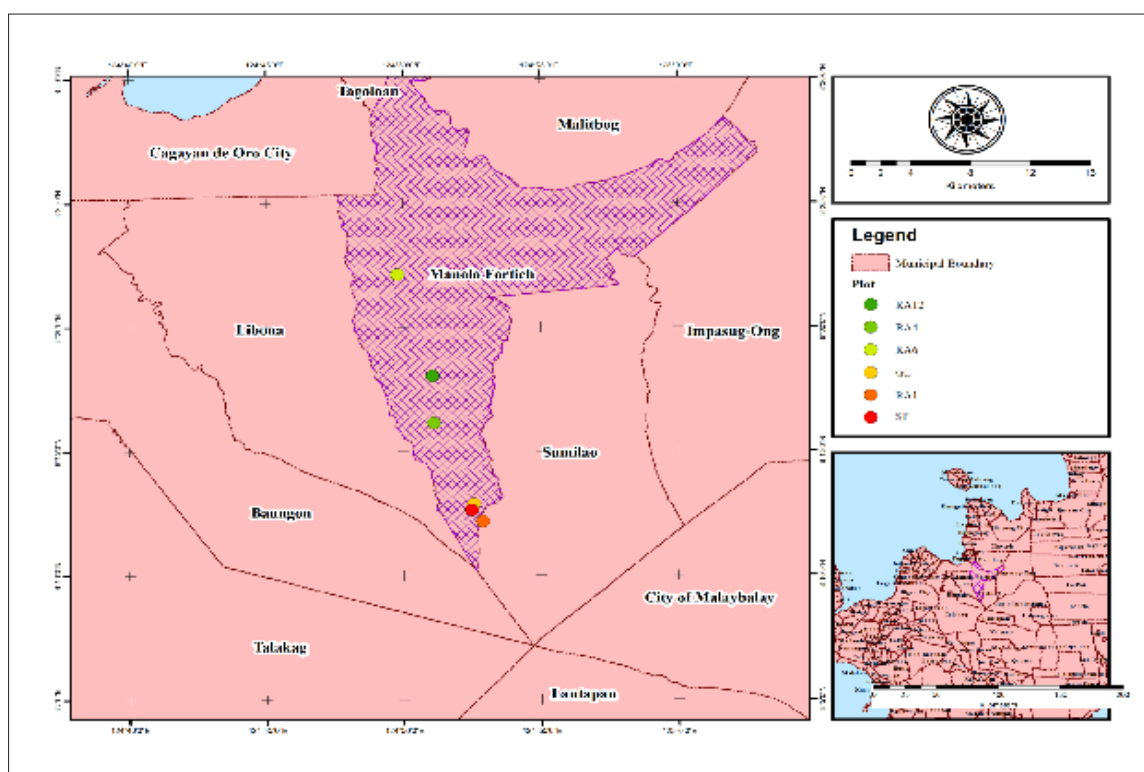


Figure 1. Location of the study sites.

Table 1. Site description of the study sites.

Site	GPS location	Transect compass reading	Position in landscape	Land-use
GL	NL: 8°12'53" EL: 124°52'33"	ES113°	Upper slope to the crest of a hill	grassland
RA1	NL: 8°12'11" EL: 124°52'52"	S185°	Upper slopes	Grassland with <i>Calliandra</i>
RA4	NL: 8°16'9" EL: 124°51'6"	W277°	Lower slopes	<i>Calliandra</i> dominated
RA6	NL: 8°22'8" EL: 124°49'48"	W282°	Lower slopes	<i>Calliandra</i> dominated
RA12	NL: 8°18'2" EL: 124°51'3"	S160°	Lower to mid slopes	Secondary forest
SF	NL: 8°12'38" EL: 124°52'28"	ES143°	Stream channel	Secondary forest

Note: GL: grassland, RA1: 1-yr-old, RA4: 4-yr-old, RA6: 6-yr-old, RA12: 12-yr-old, SF: secondary growth forest

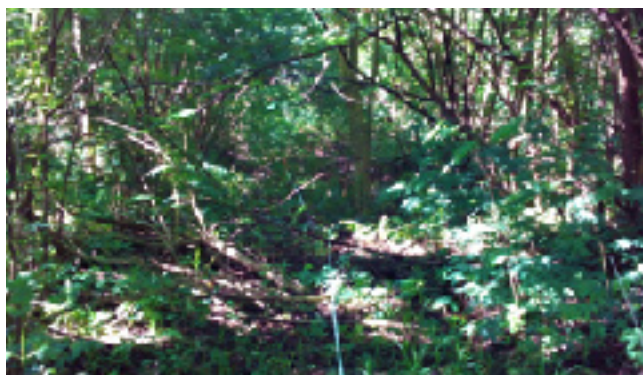
Table 2. Schedule of activities for using *Calliandra* in watershed rehabilitation (Source: Hineleban Foundation, Inc.)

Activities	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7–11	Year 12
Survey and Mapping	x								
Pre-plant brushing	x								
Clearing and hole digging	x								
Planting of seeds	x								
Uprooting of seedlings	x								
Transplanting of seedlings	x								
Line brushing			x	x					
Trimming of branches			x	x		x	x	x	
Pruning of <i>Calliandra</i>			x	x		x	x	x	
Interplanting of premium species					x				
Green manure incorporation			x	x	x	x	x	x	x

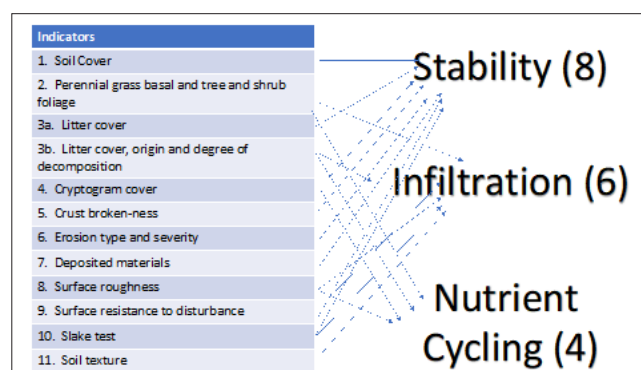
Soil surface assessment (SSA)

The soil surface condition was rapidly assessed using simple visual attributes. Each attribute is a single piece of information that acts as a surrogate (indicator) for an environmental variable or process, in this case, the biogeochemical functioning of the landscape (DENR &UPLB, 2014).

Using the SSA, 10 simple indicators were assessed visually and compared with the manual of Tongway & Hindley (2004a). These indicators include: 1) rain splash protection, 2) perennial vegetation cover, 3) amount, origin, and degree of decomposition of plant litter, 4) cryptogam cover, 5) crust brokenness, 6) soil erosion type and severity, 7) deposited materials, 8) soil surface roughness, 9) surface nature, as well as 10) slake test and texture.

**Figure 2.** Transect line being laid out in a *Calliandra* rehabilitated site.

The different indicators that explain the biogeochemical functions, like stability, nutrient cycling, and infiltration status of the sites, are found in **Figure 3**.

**Figure 3.** Contributions of the SSA indicators to landscape functions.

Stability, infiltration/runoff, and nutrient cycling has been defined by Tongway & Hindley (2004a). Stability is the ability of the soil to withstand erosive forces and to reform after disturbance. It is based on crust brokenness, surface resistance, slake test, erosion type and severity, deposited materials, cryptogam cover, soil cover, and litter cover. Infiltration/runoff is defined as how the soil partitions rainfall into soil-water (water available for plants to use) and runoff water which is lost from the local system or may also transport materials (soil, nutrients, and seed) away. The infiltration index is the ability of the soil to partition rainfall into soil-water (available for plants to use) and runoff water (lost from the system and

could transport soil, nutrients, and seeds out of the system). Indicators for infiltration/runoff include perennial basal, shrub, and tree canopy cover, surface roughness, slake test, litter cover, origin and decomposition, surface resistance to disturbance, and soil texture. Nutrient cycling status is defined as how efficiently organic matter is cycled back into the soil. Indicators for nutrient cycling include perennial basal, shrub, and tree canopy cover, litter cover, origin and decomposition, cryptogam cover, and surface roughness.

RESULTS AND DISCUSSION

Research area characterization

According to Mr. John Perrine, founder of the HFI, who pioneered the planting of *Calliandra* in 2002, *Calliandra* was planted to suppress cogon and *talahib*, which abound in the area (Personal communication, 2014). Cogon burns quickly during the dry season in the area that destroys vast areas of corn fields. Subsequent planting of timber species was done when the area was free from cogon and *talahib*, which was done in Year 4.

Table 1 shows the vegetation characterization in the study area. The dominant vegetations found in the GL are cogon (*I. cylindrica*), *makahiyang lalaki* (*Mimosa invisa* C. Mart.), napier (*Pennisetum purpureum* Schumach.), *crotolaria* (*Crotolaria juncea* Linn.), mint (*Mentha arvensis* Linn.), *takip-kuhol* (*Centella asiatica* Linn.), and Philippine ground orchid (*Spathoglottis plicata* Blume).

Plant species in RA1 were comparable to the GL area, where cogon, napier, *makahiya*, and Philippine ground orchid were also found. In addition, carabao grass (*Paspalum conjugatum* Linn.), centrosema (*Centrosema pubescens* Benth.), and *gapas-gapas* (*Camptostemon philippinense* (Vidal) Becc.) were also found.

RA4 is dominated by *Calliandra* and African tulip (*Spathodea campanulata* P. Beauv.), *biserata* [*Nephrolepis biserrata* (SW.) Schott], carabao grass (*P. conjugatum*), and *hagonoi* [*Chromolaena odorata* (Linn) R.M. King & H. Rob]. During Year 4 (RA4), interplanting at 4m x 4m of white lauan (*Shorea*

contorta Vidal) was done. The current density of planted seedlings is 10,625 ha⁻¹.

Calliandra dominates RA6 with large trees of African tulip and rain tree (*Samanea saman* Jacq. Merr.) that were present earlier in the area. Also, *hauili* (*Ficus hauili* Blanco) *biserata*, *hagonoi*, and centrosema can be found in the area. There was no interplanting at Year 4 of premium species for RA6. The current density of planted seedlings is 10,000 ha⁻¹.

RA12 is interplanted by timber species, mostly of big leaf mahogany (*S. macrophylla*), white lauan [*Shorea palosapis* (Blanco) Merr.], *A. mangium*, *Cassia spectabilis* DC., *G. arborea*, and *Calliandra*. The secondary forest floor is composed of litter, branches and seedlings, and shade-tolerant species like *gabi* (*Yautia* sp.) and edible fern [*Diplazium esculentum* (Retz.) Sw.]. The current density of planted seedlings is 725 ha⁻¹.

The standard management practice in all these rehabilitation sites includes those performed before, during, and after plantation establishment. Activities conducted prior to plantation establishment included survey and mapping and pre-plant brushing, clearing and hole digging, and seedling propagation. Surveys and mapping were initially done to evaluate an area's topography, slope, and vegetation and plan for subsequent activities like brushing, orientation, and planting location. Once location and orientation were finalized, pre-plant brushing was done by clearing a 1 m length perpendicular to the slope orientation of the area, and staking and hole digging followed.

Seeds were planted and grown to a height of 2 m before uprooted as bare root seedlings and transplanted in the field.

Plantation establishment practices included lifting seedlings, transporting bare root planting materials to the field, and transplanting in the field. Bare root planting materials were subjected to 75% leaf trimming and mud puddling to reduce the transpiration of the seedlings. The use of bigger seedlings was necessary to give the

Calliandra a head start over the aggressive grasses growing in the area.

Post-plantation establishment included line brushing, and was done in Years 2 and 3 to free the *Calliandra* from vines that may have strangled or impeded their growth. Trimming of branches and pruning began in Year 2 and continued until Year 11. The herbage materials from trimming and pruning were left on the litter floor to serve as green manure and mulching material. Interplanting of premium timber species was done in Year 4.

SF was dominated by bitaog (*Calophyllum blancoi* Pl. & Tr.), kulasi (*Lumnitzera racemosa* Willd.), balakbakan/tanguile (*Shorea polysperma* (Blanco) Merr.), gango (*Melia dubia* Cav), tree fern (*Cyathea* sp.), *Medinilla* sp., *Shorea contorta* Vidal, red lauan (*Shorea negrosensis* Foxw.), white lauan, kalingag (*Cinnamomum mercadoi* S. Vidal), and duguan (*Myristica philippinensis* Lam.). No other management practices exist except regular forest protection patrols in the SF.

Landscape organization index (LOI)

The landscape organization index (LOI) explains the proportion of the total length occupied by patches into the whole length of the transect line. In contrast, the Patch Area Index (PAI) explains the proportion of the total area occupied by patches to the maximum area within a landscape being assessed (Tongway & Hindley, 2004a). The average interpatch length is a measure of the length of the area that allows the escape of resources like water and soil. The presence of patches and interpatches greatly influences the landscape function of the study area (Van der Walt *et al.*, 2012).

The computed values of LOI showed an increasing trend across the study sites (Table 3), except for RA4 (0.65) which had a lower LOI compared with RA1 (0.71). The relatively lower values of LOI in RA4 (0.65) were influenced by the longer interpatches when the disturbance was caused by the interplanting of timber species in Year 4. Moreover, since there was no interplanting done on RA6 when it was four years old, there was no disturbance on the site; hence no interpatch was created, and escape of resources was restricted.

Table 3. Landscape organization parameters.

Parameters	GL	RA1	RA6	RA4	RA12	SF
Patch area index	0.20	0.40	1.0	0.28	1.0	1.0
Landscape organization index	0.55	0.71	1.0	0.65	1.0	1.0

Note: GL: grassland, RA1: 1-yr-old, RA4: 4-yr-old, RA6: 6-yr-old, RA12: 12-yr-old, SF: secondary growth forest

RA12 and SF had an LOI of 1.0, indicating that all the zones within the transect and the whole RA12 and SF areas being assessed were patches, and there were no interpatches. The advanced *Calliandra* regeneration patch in RA12 is covered with grasses, branches, and sometimes stones. These patches efficiently prevented the movement out of the system's precious rehabilitation resources like soil and water.

Landscape organization parameters for the different rehabilitation sites showed that RA6 (1.0) and RA12 (1.0) were comparable to SF (1.0) in terms of LOI. There were no interpatches in the RA6, RA12, and SF areas indicating possibly reduced loss of precious resources from the area. The work of Johnston (2013) in New South Wales, Australia, showed a noticeable increase in LOI for three years, albeit negligible variations in landscape functions. According to the Commonwealth of Australia (2006), the plant's foliage and the addition of litter on the soil surface obstruct the detachment of soil particles by protecting the immediate surface from splash erosion.

Soil surface assessment (SSA)

Soil surface assessment (SSA) yields the LFA indices on stability, infiltration, and nutrient cycling. Based on the soil surface assessment (SSA) results of the study areas, there was a considerable restoration of vital ecosystem functions six years after *Calliandra* planting. The canopy cover from the *Calliandra* during planting desired species at Year 4 provided shade and protection for the newly planted seedlings.

Calliandra has a dense canopy that supplies organic matter to the soil through its shed leaves, twigs,

and small branches. An increase in soil organic matter in four years has made the system more stable with no interpatches and possibly reduced nutrient leakage in sloping areas. The presence of organic matter is enough to reduce the loss of seeds, nutrients, and water from the system. Adding organic matter to the soil improved the bulk density of the soil and increased available water content, thus enhancing greater root proliferation of the coconut palm (Liyanage *et al.*, 1996). While the results of Liyanage *et al.* (1996) were done in coconut, it was assumed that *Calliandra* might have the same effect on other perennials.

LFA indices on stability

Results showed that all the sites' stability indices were significantly different using ANOVA (Table 4). GL has the lowest stability index at 47.19 and was significantly lower than all the rehabilitation sites and SF. The stability index for RA1 (61.95) and RA6 (69.44) were not significantly different. Both sites were pure *Calliandra* stands, having the same planting density at 1,000 plants ha⁻¹. The stability index for RA4 (80.12) and RA12 (82.99) were comparable to the value for SF (84.72), both sites having been interplanted with late-successional species at Year 4. RA4 (80.12) has a significantly higher stability index than RA6 (69.44) because RA6 was purely *Calliandra* and has not yet been interplanted with late-successional stage species. The interplanting of late-successional stage species in RA 4 means higher plant density and may have contributed to the higher organic matter accumulation in the sites, which protected the soil against the impacts of raindrops and served as an insulation layer for the soil surface, preventing detachment of soil particles (Schoonover & Crim, 2015).

Results of the study showed that rehabilitated areas have increased stability and infiltration indices, which is consistent with the findings of Putra *et al.* (2017) and Ampt & Doornbos (2010). Also, Geddes & Dunkerley (1999) reported that the influence of organic matter limits soil splash from beneath shrubs. Further, Ampt & Doornbos (2010) concluded that improved landscape functions could lead to improved soil physical

Table 4. Contribution of the study areas to the whole landscape.

Treatment plots	Stability index	Infiltration index	Nutrient cycling index
GL	47.19 ^a	21.31 ^a	15.33 ^a
RA1	61.95 ^b	40.44 ^b	34.47 ^b
RA4	80.12 ^c	52.08 ^c	43.23 ^c
RA6	69.44 ^b	50.79 ^c	49.73 ^c
RA12	82.99 ^c	61.52 ^d	57.20 ^d
SF	84.72 ^c	79.82 ^e	79.82 ^e

Note: GL: grassland, RA1: 1-yr-old, RA4: 4-yr-old, RA6: 6-yr-old, RA12: 12-yr-old, SF: secondary growth forest. Means in a column with the same letter are not significantly different at $\leq 5\%$ using DMRT.

and chemical properties, more growth of plants and micro-organisms, and a more sustainable landscape.

LFA indices on infiltration

The infiltration indices of the different rehabilitation sites (RA1, RA4, RA6, and RA12) were analyzed and compared (Table 4). The ANOVA results showed significant differences in the infiltration index among the different treatment plots. Using the Duncan Multiple Range Test (DMRT), the infiltration index for GL (21.31) was significantly lower when compared with the rehabilitated sites and SF, while RA1 (40.44) has higher infiltration index when compared to the grassland. The early presence of trees contributes to the infiltration of water and nutrients into the soil due to roots breaking up the soil column. RA4 (50.08) and RA6 (50.79) were comparable in infiltration index. The late-successional species interplanted in Year 4 has yet to significantly contribute to the infiltration of the site as it was planted in Year 4. The infiltration index for RA12 (61.52) was significantly higher than the other rehabilitated sites (RA1, RA4, and RA6). However, these rehabilitated sites were lower than the infiltration index of the SF (79.82), indicating that even a 12-year-old rehabilitated site has yet to reach a highly functional infiltration capacity relative to a reference forest. While grassland influences infiltration (Van der Walt *et al.* 2012), there appears to be more influence on *Calliandra*. The infiltration indices for the rehabilitated sites (RA1, RA4, RA6, and RA12) indicate that interplanting leguminous perennials like *Calliandra* can improve infiltration when the soil is starting to improve in its soil permeability,

possibly due to increased root growth. Increasing root growth enhances soil permeability by inducing the formation of the soil macropore system, also called rhizopores (Ghestem *et al.*, 2011).

The SF floor composed of litter and small logs/branches contributed to a significantly higher infiltration index (SF = 79.82) than all the rehabilitated sites (RA1 = 40.44, RA4 = 52.08, RA6 = 50.79, and RA12 = 61.52). The higher value of organic matter (OM) may have contributed to higher infiltration in SF compared with the other study sites (Figure 4). Increased perennial and ground cover improved function through higher infiltration in pasture areas (Ampt & Doornbos, 2010) and mining reclamation/rehabilitation areas (Putra *et al.*, 2017; Calalo, 2017; Van der Walt *et al.*, 2012; Smits, 2008). Ilstedt *et al.* (2016) also explained that soil infiltration was improved by trees through litter inputs and roots, promoting higher activity of soil animals by enhancing organic matter content, topsoil aggregation, and macro porosity. The results indicate that additional management inputs to a 12-year-old rehabilitation site described here are still needed to reach the infiltration index of a secondary forest.

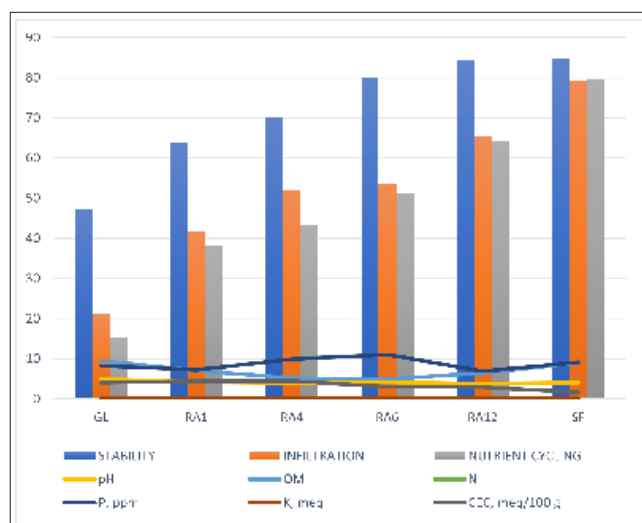


Figure 4. Landscape function analysis (LFA) indices on stability, infiltration, and nutrient cycling compared with the soil fertility status of the study sites.

LFA indices on nutrient cycling

The rehabilitation areas showed significantly different nutrient cycling indices when analyzed using ANOVA (Table 4). GL had the lowest nutrient cycling index at 15.33 compared to all rehabilitated sites (RA1, RA4, RA6, and RA12). Nutrient cycling for RA1 (34.447) was significantly higher than the nutrient cycling index of GL. Interplanting trees showed an increased nutrient cycling index even at Year 1 (RA1). The nutrient cycling index of RA4 (43.23) and RA6 (49.73) were comparable. The interplanting of late-successional species has not yet contributed significantly to the nutrient cycling of the site. The more advanced rehabilitation site of *Calliandra* stands (RA12 = 57.20) contributed more litter and organic matter to the soil but is significantly lower than the nutrient cycling index of the SF (79.82). The results indicate the ability of the 1-year-old rehabilitation site to improve the nutrient cycling index compared with a GL or a site without *Calliandra*. Greater litter production and organic matter build-up, as shown by the higher OM in RA12, are necessary to improve the nutrient cycling ability of a rehabilitation site, which appears to be happening in the more advanced rehabilitation sites. It is also worth mentioning that even the older rehabilitation sites need to be protected from soil erosion that could significantly remove litter and organic matter build-up. This is critical in managing sites on steep slopes or with high erodibility.

Water is crucial to nutrient cycling and forest productivity (Read & Lawrence, 2003). The role of litter nutrients in secondary forest recovery may be especially critical in dry tropical forests, where seasonal pulses of nutrients in litterfall constitute one of the most important aspects of the entire nutrient cycle (Campo *et al.*, 2001; Lugo & Murphy, 1986; Lambert *et al.*, 1980).

Contribution of *Calliandra* to landscape functions

The gap between the function of SF and the different study areas indicates that the restorative benefits from *Calliandra* have yet to be realized and need to grow more to approximate the SF's biogeochemical functioning (Figure 5). The stability index of RA12 (82.99) is approaching that

of the SF (84.72), as exhibited by the narrow gap between the two lines on the graph, and the results of the ANOVA are shown in **Table 4**. This could be attributed to the accumulated litter on the forest floor that prevents the escape of resources from the system, protects the soil against the direct impact of rainfall, and consequently minimizes soil detachment and erosion. Organic litter stabilizes soil particles against the raindrop splash effect (Parwada & Toll, 2019). Late successional species in RA12 contribute to developing a stratified forest structure, which is important in interception and stemflow that reduces rainfall's direct impacts and allows more time for infiltration through reduced surface run-off. Infiltration and nutrient cycling indices are higher for the SF (79.82 and 79.82) than RA12 (61.52 and 57.20). This could indicate that infiltration is more favorable in SF due to trees with deep roots that help enhance soil permeability and eventually infiltrate water into the soil. The high amount of forest floor litter in RA12 and SF plots improves soil permeability (Walsh & Voigt, 1997). Likewise, macropore channels formed by roots and soil faunal activities also enhance soil permeability and infiltration (Anderson & Spencer, 1991; Lal, 1987).

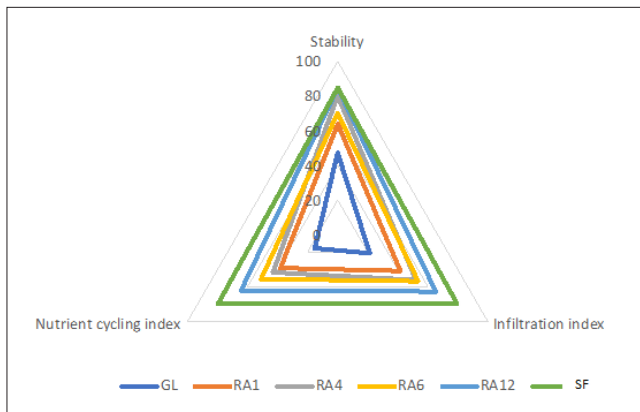


Figure 5. Approximation of the different rehabilitation areas' biogeochemical functions compared with the grassland (GL) and secondary growth forest (SF).

Figure 6 shows the likely trajectory of the restoration of grasslands in the study sites using pioneer species that can colonize and make the area favorable for planting late-successional species. While the study used *Calliandra* as the pioneer species, other pioneer species like *anabiong* [*Trema orientalis* (L) Blume] available in the area can also

be utilized. Overall, the rehabilitation of degraded sites using pioneer species (in this case, *Calliandra*) appears to exhibit a progressive upward trend to approximating the landscape functions of SF. The stability, infiltration, and nutrient cycling are increasing through time, as indicated by the increasing indices in the rehabilitated sites.

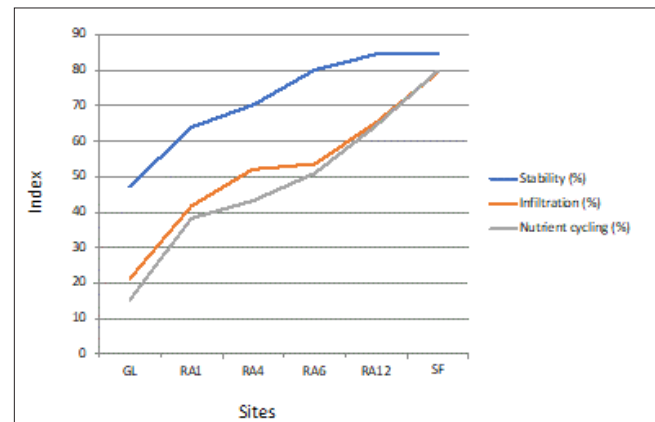


Figure 6. Contribution of the different study areas to the whole landscape.

In **Figure 5**, the progression of the various landscape function indices follows a growth-like curve or S-curve. The GL site and, to a certain extent, RA1 may be considered in the lag phase regarding its biogeochemical functions. RA4, RA6, and RA12 exhibit exponential improvement in infiltration and nutrient cycling indices. Stability indices for RA12 and SF were in the diminishing or stationary phase, with the exponential phase occurring in RA4 to RA6.

The LFA indices of this study showed that stability, infiltration, and nutrient cycling indices of the rehabilitated sites were higher than the indices for the GL, but were lower for the SF. While rehabilitated sites exhibited increased biogeochemical function, these indices were lower than those of an SF, indicating the need for continued management interventions to achieve ecosystem functions comparable to the SF/reference forest.

According to Haagner (2009), infiltration and nutrient cycling were increased by increasing perennial cover and promoting litter decomposition. Enhancement of perennial cover

can be done through mulching (Smits, 2008), rehabilitation using tree species (Calalo, 2017; Sholihah & Sjarmidi, 2014), and rotational grazing (Ampt & Doornbos, 2010).

Study results showed that rehabilitation in degraded grasslands using *Calliandra* coupled with proper silvicultural interventions had increased the perennial cover, root-induced infiltration, organic matter decomposition, and growth of cryptogam (Smits, 2008; Haagner, 2009; Ampt & Doornbos, 2010; Sholihah & Sjarmidi, 2014; Calalo, 2017). Also, benefits derived from planting *Calliandra* include reduced labor cost for weeding while attaining benefits like fuelwood, honey, and fodder production and environmental services like carbon sequestration (de Luna *et al.*, 2020).

ITTO (2002) stated that one of the forest restoration and rehabilitation criteria is the general improvement in local soil fertility, hydrological conditions, and the quality of the water supply. Results showed that rehabilitating degraded watershed areas with trees and proper management practices brought back the ecosystem's functions as early as one year after planting with a stability index of more than 50. RA4 improved the infiltration index by more than 50, and RA6 improved nutrient cycling by more than 50.

CONCLUSIONS

Calliandra was used as a pioneer species to colonize a grassland in the study site prior to planting of preferred or late-successional species. The LFA was demonstrated to be useful in assessing the rehabilitation progress of degraded watersheds planted with *Calliandra* in terms of the enhancement of stability, infiltration, and nutrient cycling indices in the study sites (GL, RA1, RA4, RA6, RA12, and SF) and determine if the use of *Calliandra* can facilitate the restoration of the ecosystem functions of the rehabilitation sites compared with that of a secondary forest. The GL site was considered the time "zero" for rehabilitation, while the SF served as the reference site.

The study showed that planting *Calliandra* and proper silvicultural practices to rehabilitate degraded ecosystems could potentially restore the ecosystem functions (stability, infiltration, and nutrient cycling) of grassland to move towards a second-growth forest. The indices for stability, infiltration, and nutrient cycling in rehabilitation sites of varying ages were increasing from Year 1 to Year 12. The values of various indices from the youngest (RA1) rehabilitation sites to the oldest (RA12) were increasing and higher than the indices in GL, conceivably due to the planting of *Calliandra*, among other vegetation, and proper silvicultural practices.

The use of pioneer species to colonize an area for rehabilitation appears to facilitate restoring the landscape functions of marginal areas like grasslands back to levels similar to that of a secondary forest or reference forests.

Successful rehabilitation of marginal grasslands could be facilitated by planting fast-growing species that can colonize the area and achieve fast canopy closure and incorporating proper silvicultural/management practices. In the absence of available seeds for colonizing large grassland areas in the Philippines, the use of exotic *Calliandra calothyrsus* as a pioneer species could be an option. Once the canopy of the *Calliandra* has risen above the Imperata grassland, planting of desired timber species can commence.

ACKNOWLEDGMENT

This article is part of the Ph.D. dissertation of the senior author. Funding for the conduct of this study was provided by the Hineleban Foundation, Inc. located in Manolo Fortich, Bukidnon, through Mr. John Perrine.

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