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Vulnerability of Araceae to social-ecological activities in Kinabalu UNESCO Global Geopark, Sabah, Malaysia

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Abstract

Biodiversity has increasingly been challenged by environmental changes, particularly in protected areas where species are often endemic and sensitive to the environmental changes. Changes in this habitat expose organisms to vulnerability. Araceae, one of the most species-rich plant families, is widely distributed in the Kinabalu Geopark and is utilized by local communities for food, medicine, and ornamental purposes. However, its survival is increasingly threatened by climate-related stressors and human activities. This study assesses the vulnerability of Araceae to social-ecological activities across six study areas (Poring, Monggis, Serinsim, Nalapak, Sayap, and Losou Podi) using a modified Coastal Integrity Vulnerability Assessment Tool (CIVAT) and Social-Ecological Resilience (SER) framework. The assessment incorporated three key components: exposure, sensitivity, and adaptive capacity. Results reveal that Losou Podi, Sayap, Monggis, and Nalapak exhibited low vulnerability, while Poring and Serinsim scored medium vulnerability due to pressures from tourism and illegal harvesting. These results highlight the effectiveness of current conservation measures within the park but also emphasize the need for targeted interventions in more vulnerable zones. Given these findings, this study provides a baseline for conservation strategies tailored to enhance Araceae resilience under climate stress.

Keywords: Araceae, climate change, Kinabalu Park, protected area, vulnerability assessment

Introduction

Araceae or the Aroid in laid man terms as proposed by the Malaysian residents, commonly referred to as the '*keladi*' is a plant identifiable according to its flowers of spathe and spadix, either as unisexual or bisexual plants (Mayo et al., 1997). Araceae comprises different life forms such as mesophytes, hemiepiphytes, epiphytes, lithophytes, rheophytes, helophytes, geophytes, submerged aquatics, or free-floating aquatics. Due to these different life forms ecological diversity, certain species are highly specialized and can only survive under specific environmental conditions. Globally, the Araceae family consists of more than 104 genera and over 3,300 species. In Sabah alone, Wong and Joling (2021) and Harisin et al. (2021) have listed at least 239 Araceae species that have been recorded in Sabah, including 125 species yet to be identified.

In Kinabalu UNESCO Global Geopark, Araceae are potentially at risk because the mountainous land is remote in relation to the lowland forests (Camacho-Sanchez et al., 2019; Danielyan, 2023). Organisms inhabiting these mountainous areas are somewhat trapped and cannot easily migrate to lower areas, except to higher elevations due to the cooler temperatures in the mountains (Razgour et al., 2021). Climatic phenomena such as El Niño, associated with increasing environmental temperatures and reduced air humidity (Wooster et al., 2012), contribute to increased temperatures around Kinabalu UNESCO Global Geopark. This condition has led to natural habitat destruction, including wildfires in several locations within the Kinabalu UNESCO Global Geopark, causing damage to the ecosystem and destroying the natural habitat of flora and fauna, especially the wild Araceae (Kudo & Kitayama, 1999).

Traditional forest harvesting practices have been inherited by the indigenous people of North Borneo from the Dusun ethnic community (Muhammed & Muthu, 2015). However, wild Araceae populations in Kinabalu Park are now increasingly impacted by nearby community activities. Plant species with significance in the daily lives of communities often have a broader geographical distribution compared to species not in use by those communities, due to intentional cultivation and management (Acebey et al., 2010). In the case of Araceae, various species are harvested for food, medicinal use, ornamental purposes, and other traditional applications (Fatiha *et al.,* 2021; Muhammed & Muthu, 2015; Titus et al., 2012). Among the harvested Araceae is *Schismatoglottis ahmadii*, used for food consumption (Awang-Kanak, 2021; Muhammed & Muthu, 2015).

The increased access to commercial food sources has led to a reduction in harvesting activities (Gan et al., 2020). However, the habitat of wild Araceae remains highly vulnerable to socio-ecological activities, particularly due to the clearing of nearby forest areas for permanent agriculture, such as oil palm and rubber plantations, as compared to subsistence farming of crops like rice and vegetables (Martin et al., 2002). This exposes Araceae to high light intensity, resulting in elevated temperatures and reduced relative humidity, the conditions that do not reflect the natural habitat characteristics of Araceae. The combination of community activities and the resulting changes to habitat conditions poses a significant threat to the survival of Araceae and may disrupt the ecological balance of their natural ecosystems (Shumsky et al., 2014).

Despite the high diversity and ecological importance of Araceae in Sabah, particularly within Kinabalu UNESCO Global Geopark, their habitats are increasingly threatened by both climate change phenomena and social-ecological pressure, including land conservation for agriculture and community harvesting practices. These disturbances have altered the natural environmental conditions essential for Araceae survival. However, currently no comprehensive assessment of Araceae has been conducted within Kinabalu Park. Such an assessment is crucial to inform mitigation strategies for habitats within the park. Therefore, this study aims to identify the vulnerability level of Araceae to social-ecological activities within the Kinabalu Park area and its surrounding borders by adapting and modifying standard vulnerability assessment tools.

Method and study area

Study area

The field survey was conducted from May 29 to June 4 of 2023 to validate the status of Araceae and assess its vulnerability to social-ecology in the Kinabalu UNESCO Global Geopark. The study site covers six locations within the management area of Kinabalu UNESCO Global Geopark (Figure 1); namely A (Losou Podi) (6.342629° N, 116.621312° E), B (Sayap) (6.14487° N, 116.5681° E), C (Poring) (6.064751° N, 116.690599° E), D (Monggis) (6.1997° N, 116.74815° E), E (Serinsim) (6.29203° N, 116.695454° E) and, F (Nalapak) (6.48013° N, 116.63612° E). The total area of Kinabalu Park is approximately 475 km², making it a reservoir of high biological diversity (Beaman & Beaman, 1998). Kinabalu Park was designated as a World Heritage Site in 2000 to conserve and preserve the flora and fauna within its boundaries. It was futher recognized as a UNESCO Global Geopark in 2023. This park is adjacent to hundreds of villages of indigenous people of North Borneo, who rely on the nearby forest for their daily activities and livelihoods.

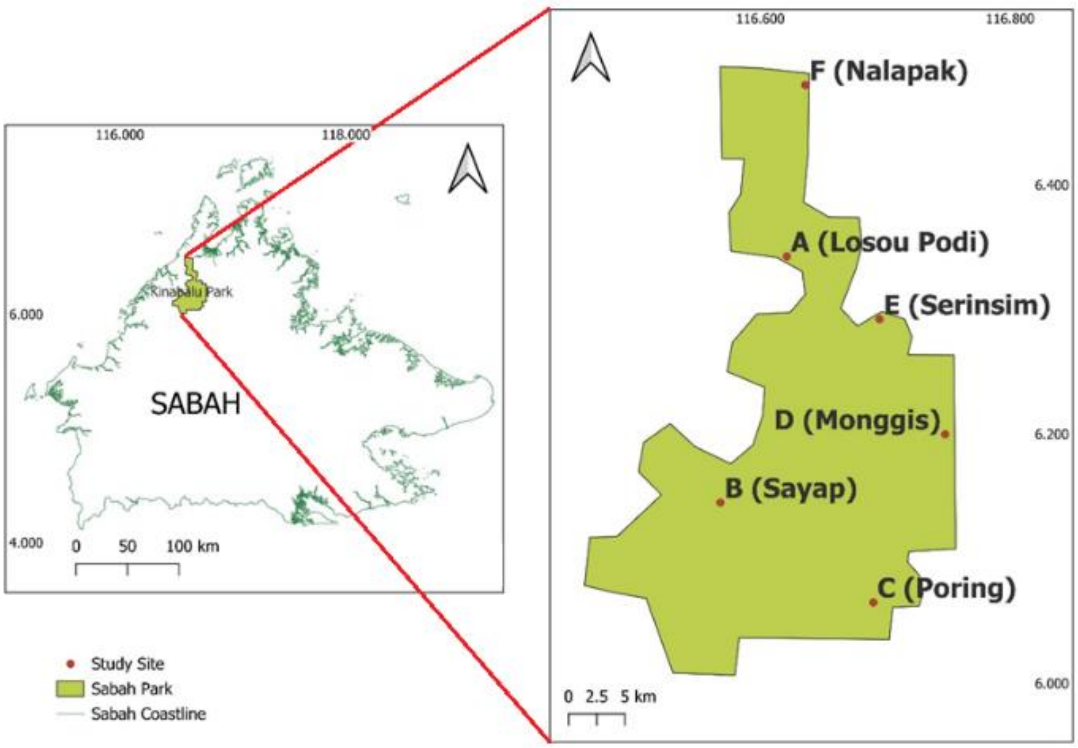
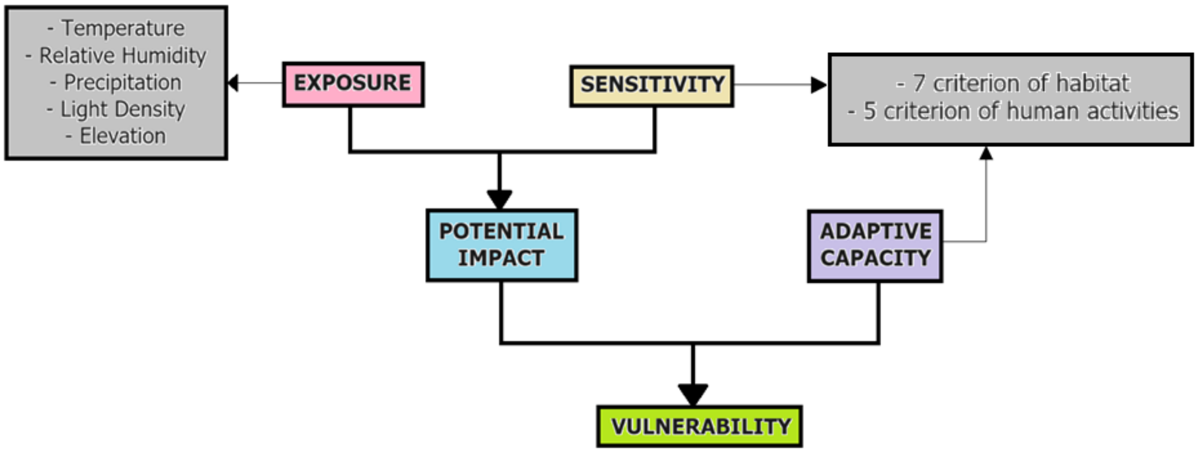


Figure 1. Location of site visit areas around Kinabalu UNESCO Global Geopark

Social-ecological activities assessment on Araceae

The assessment employed in this research is a combination of adapted and modified from the Coastal Integrity Vulnerability Assessment Tool (CIVAT) developed by Siringan et al. (2012), and the Social-Ecological Resilience (SER) framework proposed by Sowman and Raemaekers (2018). CIVAT is structured around three main components (Figure 2), namely exposure, sensitivity, and adaptive capacity, which are also detailed in Appendices A, B, and C respectively. These components evaluate the potential impact of climate change (IPCC, 2007). Meanwhile the SER framework is used to examine the extent to which community activities affect the habitat and ecosystem of Araceae, allowing for the identification of species specific adaptive responses (Shumsky et al., 2014). The criteria for each component were modified to reflect the environment characteristics specific to Araceae, referencing studies by Acebey et al. (2010), Boyce et al. (2010), Noor Liyana et al. (2020), Wong and Joling (2021), Zulhazman (2020), Zulhazman, Abas, et al.

(2021), and Zulhazman, Aweng, et al. (2021). Each component includes several criteria scored ranging from 1 to 5, categorized as low (1 and 2 points), medium (3 and 4 points), and high (5 points). The cumulative scores across these components determine the overall vulnerability level of Araceae species in the Kinabalu UNESCO Global Geopark and inform subsequent conservation strategies.



Source: IPCC, 2007

Figure 2. Vulnerability to climate change results from the interaction of exposure and sensitivity with adaptive capacity

According to Foden and Young (2016), exposure is defined as changes in habitat and areas occupied by the Araceae species. This component includes the change of the nature and magnitude or amount of Araceae. The change encompasses both direct and indirect microclimate variables. The climatic variables applied in this study are temperature, precipitation, light density, elevation, and relative humidity based on Acebey et al. (2010), Boyce et al. (2010), Kitayama et al. (2014), Nor Rasyidah (2022), Wong and Joling (2021) and Zulhazman (2020). These are closely associated with meteorological changes and climate variability.

The sensitivity on the other hand, reflects the degree to which Araceae habitats are affected by environmental changes, particularly those induced by humans. It captures the response and resilience of the species to such changes (Glick et al., 2011). The criteria used to assess sensitivity were adapted from Baral and Ghimire (2020), Noor Liyana et al. (2020), Zulhazman (2020), Zulhazman, Abas, et al. (2021), Wong and Joling (2021), and Zulhazman, Aweng, et al. (2021) focus on habitat disturbances and ecological pressures resulting from human land use. The specific interactions between Araceae and anthropogenic factors are outlined in Table 1, with reference to works by Castellani and Sal (2012), Martire et al. (2015), and Wallenfang et al. (2015)

Table 1. Sensitivity component rubrics

Sensitivity criteria			Low (1-2)	Medium (3-4)	High (5)
	1	Microhabitat	River bank	Ridge	Waterlogged

INTRINSIC	**2**	Distant from river (m)	<400	400-800	801-1200	1201-1500	>1500
	3	Canopy cover (% seedling)	<25		25-75		>75
	4	Soil texture (geomorphology)	Boulder, sandy & good water flow	Boulder, sandy & good water flow	Sandy & dry	Clay & watery	Clay & dry
	5	Slope area (^{0})	>55	41-55	26-40	10-25	<10
	6	Forest layer	Forest floor	Understory layer	Canopy layer		Emergent layer
	7	The type of forest	Undisturbed forest/ virgin forest	Less disturbed forest (recovery)	Disturbed forest (recovery)	Disturbed forest	Very disturbed forest
EXTRINSIC	**8**	Distant to buffer zone	>2km		1-2km		<1km
	9	Ecotourism	No ecotourism activity	Ecofarm & homestay	Picnic along the river	Camping & picnicking	Trekking & hiking, camping
	10	Type of crops	Short terms (paddy, vegetable)		Mixed crops (rubber tree, fruits & vegetable)		Long terms (oil palms, rubber tree)
	11	Number of visitors	No outsider tourist		Limit the number of tourist		No limit of number for tourist
	12	Years of land used	<1	1-3	4-6	7-9	>9

Source: Castellani & Sal, 2012; Martire et al., 2015; Wallenfang et al., 2015; Baral & Ghimire 2020; Noor Liyana et al., 2020; Zulhazman, 2020; Wong & Joling, 2021; Zulhazman et al., 2021a; dan Zulhazman et al., 2021b

Adaptive capacity is defined as the ability of species, habitats, or ecosystems to mitigate or avoid the detrimental effects of meteorological factors change through mechanisms such as dispersal, colonization of more suitable areas, plastic ecological responses, or evolutionary adaptation (Foden & Young, 2016). According to Glick et al. (2011), adaptive capacity is shaped by both internal biological traits and external environmental factors. The specific criteria applied to assess adaptive capacity in this study are detailed in Table 2.

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Table 2. Adaptive capacity component rubrics

Criteria			Low (1-2)		Medium (3-4)		High (5)
INTRINSIC	**1**	The type of forest	Very disturbed forest	Disturbed forest	Disturbed forest (recovery)	Less disturbed forest (recovery)	Undisturbed forest/ virgin forest
	2	Forest layer	Emergent layer	Canopy layer	Understory layer		Forest floor
	3	Soil texture	Clay & dry	Clay & watery	Sandy & dry	Boulder, sandy & good water flow	Boulder, sandy & good water flow
	4	Slope area $(^0)$	<10	10-25	26-40	41-55	>55
	5	Distant to the close river (m)	>1500	1201-1500	801-1200	400-800	<400
	6	Canopy cover (% seedling)	>75		25-75		<25
	7	Microhabitat	Waterlogged area		Ridge		River bank
EXTRINSIC	**8**	Years of land used	>9	7-9	4-6	1-3	<1
	9	Type of crops	Long terms (oil palms, rubber tree)		Mixed crops (rubber tree, fruits & vegetable)		Short terms (paddy, vegetable)
	10	Tourist's activities	Trekking & hiking, camping	Camping & picnicking	Picnic along the river	Ecofarm & homestay	No ecotourism activity
	11	Number of tourist	No limit of number for tourist (>4000 per year)		Limit the number of tourist (<4000 per year)		No outsider tourist
	12	Infrastructures for tourist	Permanent infrastructures (toilet & resort)		Trail with boardwalk		Trail without boardwalk

	13	Compliance with the land use by the villagers	Self-sustaining crops and livestock	Land use according to the requested area	Excavation and hill cutting

Source: Castellani & Sal, 2012; Martire et al., 2015; Wallenfang et al., 2015; Baral & Ghimire 2020; Noor Liyana et al., 2020; Zulhazman, 2020; Wong & Joling, 2021; Zulhazman et al., 2021a; dan Zulhazman et al., 2021b

Rubric scoring

Scoring information was obtained from both primary and secondary data sources. Primary data were collected through field observation at the study sites. Additionally, interviews with several local communities were carried out to gather information on the environmental changes and developments within the study sites. Interviews were also conducted with Sabah Parks staff and Honorary Rangers at each substation to obtain information regarding community compliance with the laws and regulation of Kinabalu UNESCO Global Geopark. Meteorological data, including air temperature and rainfall recorded at the study sites were obtained from Sabah Parks Office and Sabah State Meteorology Department. Unstructured interviews were employed, with questions were tailored to gather information relevant to scoring each criterion of the vulnerability assessment components. Scoring was conducted using a rubric specifically designed to evaluate the vulnerability level of Araceae. The total number of key informants in the scoring process is presented in Table 3.

Table 3. Number of key informants according to the study site within the Kinabalu UNESCO Global Geopark

Study site	Location	Key informants (Sabah Park's Staff)	Key informants (Local Community)	Total key informants
A	Losou Podi	1	2	3
B	Sayap	4	2	6
C	Poring	2	1	3
D	Monggis	3	3	6
E	Serinsim	1	1	2
F	Nalapak	1	2	3
		Total		**23**

Results and discussion

Exposure of Araceae to social-ecological activities

The exposure component scores show that study sites A and B were categorized as having low exposure, while the other study sites exhibited medium exposure levels (Table 4). Across all study sites showed that relative humidity and light density were scored as low and medium, respectively. In contrast, temperature, precipitation, and elevation have varying scores, reflecting differences in geographical characteristics and human activities. A medium score (4) was recorded for temperature and precipitation criteria in study sites D and E due to the deforestation occurring near the border of these areas.

At study site D, meteorological data showed a decrease in rainfall and a concurrent increase in ambient temperature, particularly during El Niño events (Kitayama, 1999; Kudo & Kitayama, 1999). Staff members of the Kinabalu UNESCO Global Geopark and local community also reported perceiving a rise in temperature in their respective areas. This climatic change has led to adjustments to the timing of agricultural activities schedules, which are now limited to the early hours of 7:00 am to 9:00 am, compared to previous practices that extended until 11:00 am, due to increased heat.

The Kinabalu UNESCO Global Geopark consists of various forest types, including lowland Dipterocarp (0-300 m.a.s.l.), hill Dipterocarp (301-750 m.a.s.l.), upper hill Dipterocarp (751-1200 m.a.s.l. (van der Ent et al., 2016). However, Martin et al. (2002) classified the forest type within the Kinabalu UNESCO Global Geopark as tropical montane rainforest, tropical lowland rainforest, and forest on ultrabasic soils. These forested areas are characterized by high individual density per hectare (Rasyidah et al., 2021) and dense canopy cover, resulting in low light intensity, approximately 3.4-11.2 Lux reaching the forest floor (Aiba & Kitayama, 2020; Nor Rasyidah, 2022; Ushio et al., 2017). According to Wong and Joling (2021), most Araceae species thrive in areas with medium to high light intensity. The score of light density for all study sites was medium (3), indicating that low light intensity is unfavorable for the growth of Araceae within the Kinabalu UNESCO Global Geopark (Rafiqpoor & Nieder, 2006; Wong & Joling, 2021).

Table 4. Exposure scores for each study site

Study sites exposure		**Source**	**Study site scores**					
			A	**B**	**C**	**D**	**E**	**F**
1	Relative humidity	Nor Rasyidah (2022), Meteorology	1	1	1	1	1	1
2	Light density	Field observation	3	3	3	3	3	3
3	Temperature	Nor Rasyidah (2022), Meteorology	2	1	3	4	4	2
4	Precipitation	Kitayama et al. (2014), Meteorology	1	1	3	4	4	3
5	Elevation	Wong & Joling (2021), field observation	3	3	3	2	2	4
Total score			10	9	13	14	14	15
Level			**L**	**L**	**M**	**M**	**M**	**M**

Note: Green = Low (L); Blue = Medium (M); Red = High (H). A – Losou Podi; B – Sayap; C – Poring; D – Monggis; E – Serinsim; F – Nalapak

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Sensitivity of Araceae to social-ecological activities

Most study sites showed a medium level of sensitivity (Table 5), with the exception of study site D, which exhibits a low sensitivity level. Four criteria received consistently low scores across all study sites; which are microhabitat, distance to the closer river, canopy cover, and soil texture. Two criteria showed variation, with scores ranging from low to medium; which are slope, and the distance to the buffer zone. The forest layer criteria were consistently rated at a medium score. Several criteria showed scores ranging from medium to high, including forest type, crop type, ecotourism facility, and the numbers of tourists. Only one criterion showed a high score for all the study sites were the years of land used. This reflects the presence of long-term land use conflict managed by the community residing near the border of Kinabalu Park (Long et al., 2003; Martin et al., 2002).

At study site E, the dominant cultivated plant type is cash crops, particularly oil palm. While the cultivation of oil palm is known to enhance the economic status of local communities (Syahza, 2019), it also contributes to long-term ecological and ecosystem disturbances within Araceae habitats (Sheldon, 1985). Field observations indicate that study sites A, B, C, and F are characterized by mixed cultivation practices involving rubber trees, fruit trees, and vegetables. Communities residing in these sites also engaged in short-term crop rotation between paddy and vegetables.

In 1998, study site E experienced a forest fire that significantly damaged the surrounding habitat (Pegan et al., 2018). Such fires can alter species composition and biodiversity, with plant mortality rates reported between 38% and 94% (Woods, 1989). Observations at study site B clearly showed an extensive forest clearing for cultivation purposes, with the distance between managed agricultural land and the Kinabalu Park boundary estimated at 1.5 to 2.0 km perimeter.

Table 5. Sensitivity scores for each study site

		Sensitivity	**Source**	**Study site scores**					
				A	**B**	**C**	**D**	**E**	**F**
INT	**1**	Microhabitat	*Field observation	1	1	1	1	1	1
	2	Distant to the closer river (m)	*Staff, Field observation	2	1	2	1	1	1
	3	Canopy cover (% seedling)	*Field observation	1	1	1	1	1	1
	4	Soil texture (geomorphology)	Field observation	2	2	2	2	2	2
	5	Slope (^{0})	*Field observation	4	3	2	2	2	2
	6	Forest layer	*Field observation	3	3	3	3	3	3
	7	The type of forest	*Field observation, Staff	4	5	3	3	5	4
EXT	**8**	Distant to buffer zone	*Field observation, penguasa	2	4	3	2	4	2
	9	Ecotourism	*Field observation, Staff	1	4	5	4	5	2

10	Type of crops	*Field observation, Community, Staff	4	3	4	1	5	3
11	Number of tourist	*Field observation, Staff	1	3	5	3	5	3
12	Years of land used	*Community, Staff	5	5	5	5	5	5
Total score			30	35	36	28	39	29
Level			**M**	**M**	**M**	**L**	**M**	**M**

Note: *on 29-31 May 2023, and on 1-2 June 2023; Green = Low (L); Blue = Medium (M); Red = High (H). A – Losou Podi; B – Sayap; C – Poring; D – Monggis; E – Serinsim; F – Nalapak

Study site C is a highly popular eco-tourism area with hot spring pools contributing to high sensitivity score (Table 3). Additionally, the area attracts numerous visitors for water-based recreational activities at Kipungit and Langanan Waterfall. The absence of restriction on visitor numbers further elevates its sensitivity level. In contrast, study sites B, D, and E which are serving as access points to several mountains, received low to medium sensitivity scores. These sites are not heavily promoted as tourist destinations due to their geographical location. Specifically Mount Minodtuhan is located at study site B, Mount Tambuyukon at study site D, and Mount Nambuyukong at study site E. The long travel distances and poor road infrastructure have contributed to the limited ecotourism activities in study site F. Study site A, which recorded almost no tourist activity, received low score for the sensitivity component.

Ecotourism serves as a supplementary income generating activity for many local communities, particularly those offering cultural and nature based attractions (Pingking & Rosazman, 2020). Communities residing near the Kinabalu UNESCO Global Geopark gain a benefit from the increased economic opportunities presented by ecotourism, particularly in villages situated near Mount Kinabalu (Mojiol, 2019). The popularity of Mount Kinabalu as a climbing destination attracts both domestic and international tourists to the surrounding areas, leading to increased demand for accommodation in hotels and homestays offered by the local communities (Franey *et al.*, 2021). However, it is important to note that most of the study sites evaluated in this research are located outside the core ecotourism zones of the Kinabalu UNESCO Global Geopark.

Adaptive capacity of Araceae to social-ecological activities

Study sites D and F demonstrated a high level of adaptive capacity, while the remaining four study sites exhibited a medium level of adaptive capacity (Table 4). Several criteria showed varying scoring, ranging from low to medium to high. These included forest types, crop types, tourist infrastructures, tourist activities, and visitor numbers. Two criteria consistently received medium scores across all sites, which are forest layer and soil texture. Three criteria showed varied scores between medium to high, which are slope, distance to the nearest river, and canopy cover. Notably, two criteria scored high across all study sites: compliance with community land use and microhabitat of wild Araceae.

In contrast, the land use duration criterion received consistently low scores (1) for all study sites (Table 6). Long-term land use for agriculture has been linked to increased soil erosion and substantial ecological disruption. Based on the Community-Based Adaptation (CBA) approach, which focuses on enhancing adaptive capacity through integration of socioeconomic development with community livelihoods, such interventions can mitigate factors contributing to vulnerability

(Forsyth, 2013). Meanwhile, the Ecosystem-Based Adaptation (EBA) approach emphasizes climate change adaptation through the conservation and restoration of ecosystem services, offering socio-economic benefits to local communities (Locatelli et al., 2009). In this context, the application of mixed cropping systems and crop rotation can help improve soil properties and maintain nutrient availability for surrounding vegetation (Alhameid et al., 2017; Wallenfang et al., 2015). Compliance with community land use practices is high based on the Terms and Conditions for Obtaining Gardening Permits Under Section 48 (1) of the Parks Enactment 1984 (Sabah Parks, 1984). Study site A recorded the highest score for tourist infrastructure criterion (Table 4), while study sites C and E received the lowest scores, namely one. According to Nurul Athirah *et al.* (2014), less developed areas are considered to have higher adaptive capacity compared to more developed areas due to reduced infrastructure-related disturbances.

Table 6. Adaptive capacity scores for each study site

Study sites adaptive capacity			**Source**	**Study site scores**					
				A	**B**	**C**	**D**	**E**	**F**
INT	**1**	Type of forest	*Field observation, Staff	2	1	3	3	1	2
	2	Forest layer	*Field observation	3	3	3	3	3	3
	3	Soil texture	*Field observation	4	4	4	4	4	4
	4	Slope (^{0})	*Field observation	2	3	5	5	5	5
	5	Distant to the closer river (m)	*Staff, Field observation	4	5	4	5	5	5
	6	Canopy cover (% seedling)	*Field observation	5	5	4	5	4	5
	7	Microhabitat	*Field observation	5	5	5	5	5	5
EXT	**8**	Years of land used	*Community, Staff	1	1	1	1	1	1
	9	Type of crops	*Field observation, Community, Staff	2	3	2	5	1	3
	10	Tourist's activities	*Community, Staff	4	2	1	2	1	5
	11	Number of visitors	*Community, Staff	5	3	1	3	1	3
	12	Infrastructures for tourist	*Field observation	5	4	1	4	1	4
	13	Compliance with village land use	Staff	5	5	5	5	5	5
Total score				47	44	39	50	37	50
Level				**M**	**M**	**M**	**H**	**M**	**H**

Note: *on 29-31 May 2023, and on 1-2 June 2023; Green = Low (L); Blue = Medium (M); Red = High (H). A – Losou Podi; B – Sayap; C – Poring; D – Monggis; E – Serinsim; F – Nalapak

Vulnerability of Araceae to social-ecological activities

The level of potential impact was obtained based on the combined results of exposure and sensitivity levels (Table 7). Study sites C and E have a medium potential impact, while study sites A, B, D, and F were categorized as having a low potential impact. These potential impact scores were subsequently cross-tabulated with adaptive capacity components to assess overall vulnerability. The analysis revealed that study sites C and E scored a medium level of vulnerability to social-ecological activities. Both study sites are frequently visited by tourists on a daily basis. Activities such as hiking and trekking through forested areas have resulted in physical damage to individual Araceae plants and their habitats along pedestrian trails (Normah et al., 2016). However, field observations indicated that the presence of tourists did not affect Araceae habitats located outside of the main trekking routes (Figure 1: A – B).

The Kinabalu UNESCO Global Geopark authorities regularly enforce the Parks Enactment 1984 (Act No. 6 of 1984, State of Sabah) 2007 Amendment, (Kerajaan Negeri Sabah, 1984) by conducting regular patrols along the Kinabalu UNESCO Global Geopark boundaries. Moreover, communities residing near the park's border demonstrate a very high awareness regarding the importance of habitat conservation within the Kinabalu UNESCO Global Geopark. These communities comply with the Community Lot Usage regulations established by the Sabah Parks, which contributes significantly to the protection of Araceae habitats by minimizing direct human disturbances.

Table 7. Vulnerability level for each study site in the Kinabalu Park

Location (Study sites)	Exposure	Sensitivity	Potential Impact, IP (Exposure *x* sensitivity)	Adaptive Capacity, AC	Vulnerable (IP *x* AC)
A	**L**	**M**	**L**	**M**	**L**
B	**L**	**M**	**L**	**M**	**L**
C	**M**	**M**	**M**	**M**	**M**
D	**M**	**L**	**L**	**H**	**L**
E	**M**	**M**	**M**	**M**	**M**
F	**M**	**L**	**L**	**H**	**L**

Note: Green = Low (L); Blue = Medium (M); Red = High (H). A – Losou Podi; B – Sayap; C – Poring; D – Monggis; E – Serinsim; F – Nalapak

During field observation, several human activities were found to impact Araceae species. For example, Photo 1(A) shows *Rhaphidophora korthalsii* growing in the centre of a trail and being trampled by hikers heading to Mount Nambuyukong. Other Araceae individuals, such as *Scindapsus pictus* and *Schismatoglottis* sp., were also observed growing directly along pedestrian trails as shown in Photo 1(B). Natural disasters have also contributed to habitat degradation. The 2015 earthquake that struck Mount Kinabalu trigger landslides in the Kinabalu Park, resulting in the fall of large trees and destruction of native Araceae habitats, including *Ooia sayapensis* and several *Schismatoglottis* species found along the Kemantis River at Sayap Substation as shown in Photo 1(C). Additionally, agricultural activities carried out by the Sayap Village community in a disputed land area have further impacted Araceae habitats as shown in Photo 1(D).

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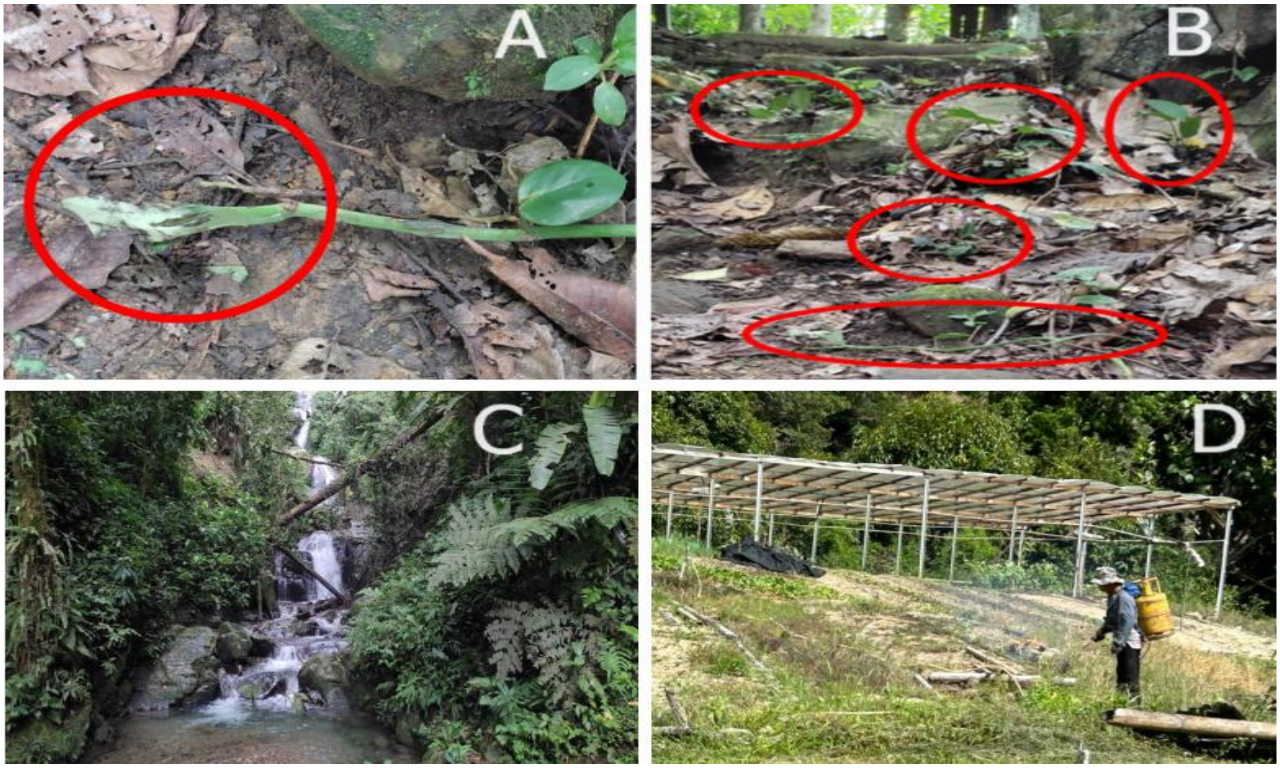

Photo 1. A – Impact of footprints on the stem of *Rhaphidophora* sp. along the trail at site E.
B – Some individuals of Araceae (highlighted in red circles) found along the trail to Nambuyukong at site E.
C – The condition of the Kemantis River at site B, which is a habitat for several wild Araceae species such as *Ooia sayapensis* and *Rhaphidophora korthalsii*, is disrupted by fallen trees due to the effects of a landslide.
D – Agricultural areas cultivated by the community within the disputed area (site B).

Conclusion

Among the six study sites, only two study sites (Poring and Serinsim) indicate Araceae habitat has medium vulnerability to social-ecology, based on medium scores for both potential impact and adaptive capacity. Meanwhile, the remaining four study sites (Losou Podi, Sayap, Monggis, and Nalapak) showed a low vulnerability to social-ecology. Monggis and Nalapak exhibited low potential impact, but with high adaptive capacity. While Losou Podi and Sayap show low potential impact, combined with medium adaptive capacity.

All study sites are located within the Kinabalu UNESCO Global Geopark area and under the jurisdiction of Sabah Parks. The presence of strict park regulations, along with strong community awareness regarding habitat protection, appears to contribute to the relatively low to medium levels of climate vulnerability observed across the study areas. Additionally, the geographical setting at the base of Mount Kinabalu results in relatively uniform environmental conditions, which may have influenced these findings. However, this assessment mainly relied on secondary data and field observations, with limited quantitative ecological and climatic data available for the specific habitat requirements of Araceae species in the study sites. This data limitation may have influenced the accuracy of vulnerability scoring. A more comprehensive assessment, including species-level ecological data, phenological monitoring, and long-term environmental data is necessary for a more robust evaluation. It is also possible that the actual vulnerability level is higher than currently estimated, particularly in the absence of sustainable human activity management within these ecosystems.

Sabah Parks play an important role in protection and preservation of the Araceae and other plants within the Kinabalu UNESCO Global Geopark. However, the lack of detailed species inventories and ecological studies represents a significant gap. Future research should aim to close these gaps through collaborative efforts between researchers, local communities, and conservation authorities. By adopting a holistic and adaptive management framework, integrating both scientific and community driven approaches, the vulnerability of Araceae to social-ecological activities pressures can be effectively mitigated to ensure the long term survival of this ecologically and culturally valuable plant.

To strengthen the conservation of Araceae within the Kinabalu UNESCO Global Geopark, several strategic actions should be implemented. First, the development of a centralized database that documents Araceae diversity, distribution, and ecological preferences is essential for supporting species-specific conservation planning. This effort should be complemented by regular biodiversity assessments to track population trends and monitor habitat changes, especially in relation to climate variability and land-use transformation. In parallel, environmental education and outreach programs must be enhanced within local communities to encourage sustainable use practices and promote stewardship of Araceae rich habitats. The adoption of Ecosystem-Based Adaptation (EBA) strategies, including forest restoration and the protection of ecological corridors, can also enhance overall ecosystem resilience. Additionally, Community-Based Adaptation (CBA) initiatives that integrate traditional ecological knowledge with scientific insights will ensure that conservation efforts are aligned with local socio-cultural values and livelihoods. Finally, the establishment of species-specific conservation zones or micro reserves, particularly in medium vulnerability sites such as Poring and Serinsim, is critical to safeguard threatened or endemic Araceae taxa.

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