

ASSESSING ECOLOGICAL INTEGRITY AND ECOSYSTEM SERVICES FOR SUSTAINABLE MANAGEMENT OF FOREST, INCORPORATING COMMUNITY INVOLVEMENT

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ABSTRACT

The social dimension of forestry is critical in harmonizing efforts towards sustainability. This study, which focuses on understanding the ecological integrity and ecosystem service (ES) supply, is a significant step towards empowering communities and bringing stakeholders together to achieve sustainable livelihoods, conservation of natural resources, and ecosystem stability. Rapid multidisciplinary research was conducted to study the ecological integrity, identify the ES present in the Tondulu Sub-Catchment Area, Kawang FR, and Tawai FR, and assess the value of these services to the local community. The study revealed that various types of land covers in the forest are significant biophysical structures in the sites, providing favorable habitats for many observed high conservation value attributes, including endemics and threatened species. Equally, the conducive soil physical and chemical conditions could support the site's ecosystem function. Findings also indicate that the presence of selected bioindicator species helps determine the supporting and regulating services at the sites. Participatory Rural Appraisal (PRA) approach, including household survey, focus group discussion, and key informant interview involving 515 households residing within and adjacent to the sites, revealed that the community valued a wide range of forest ecosystem services, including provisional, regulating, and cultural values. Development plans were perceived as one of the major threats to the ecosystem. Furthermore, the area's capacity in delivering ES was assessed using the Potential Supply of ES Matrix and the overall result is further strengthened through Geographic Information Systems (GIS) applications. This information can help integrate the ES concept and directly address community needs in revising and implementing forest management plans.

Keywords: Ecosystem Services, Ecological Integrity, Sustainability, Participatory Rural Appraisal, Potential Supply of ES Matrix, Forest Management, Geographic Information Systems, Local Community

1.0 INTRODUCTION

“Ecological integrity” provides a suitable framework for ecologically based monitoring and can provide valuable information for assessing ecosystem status and management efficacy (Tierney *et al.*, 2009). According to Parrish *et al.* (2003), ecological integrity is a measure of an ecosystem's structure, function, and composition in relation to the system's historical or natural range of variation, as well as disturbances brought about by anthropogenic or natural agents of change. Considering ecological integrity can assist managers in selecting landscape layouts that strike a balance between cultural and natural objectives and in comprehending the effects of significant local stressors like air pollution (Tierney *et al.*, 2009). The sustainable management of forest ecosystems depends critically on the intricate relationship between ecological integrity and ecosystem services. The forest is not only crucial for sequestering carbon dioxide and supporting biodiversity, but it also offers recreational opportunities, soil fertility, and water management. Ecosystem Services (ES) are the processes and conditions through which constituent biodiversity and natural ecosystems support human life. The welfare of the present and future generations relies on the continuous flow of ES, which is the benefits people gain from ecosystems (Daily, 1997). ES values are generally categorized as economic, ecological, and socio-cultural (de Groot *et al.*, 2002). Daily interactions of people with their environment resulted in values associated with ES (Millennium Assessment, MA 2005). Local communities are usually directly linked to ecosystems because they are highly dependent on local ES and are the most directly influenced by ecosystem

degradation. Active managers of the local ecosystems may also be the local communities (Folke *et al.*, 2005). Therefore, it is vital to understand how people utilize, perceive, and value various ES. Local perspectives on ES are needed to obtain an accurate assessment of the importance of ES for local people and to comprehend the factors determining social preferences and trade-offs related to land-use changes and conservation decision-making (MA 2005 & Martin-Lopez *et al.* 2012). Local communities play a critical role in defining ecological indicators and prioritizing ecosystem services that are most important to their livelihoods since they possess invaluable traditional knowledge and a solid connection to their natural environment. Stakeholder engagement at the grassroots level, helps ensure that management plans are socially equitable, culturally appropriate, and scientifically sound (Mackey *et al.*, 2023). This study focuses on understanding the ecological integrity, identifying the ecosystem service (ES) present in the area, and assessing the value of these ES to the local communities in the Tondulu Sub-Catchment Area, Kawang Forest Reserve, and Tawai Forest Reserve. GIS applications were applied to enhance the findings of the study.

2.0 PROJECT ON FOREST ECOSYSTEM SERVICES

Researchers from the Forest Research Centre, Sabah Forestry Department work together in conducting this study through scientific expeditions. This study has been conducted in three sites, which are located in the (1) Tondulu Sub-Catchment Area in Tambunan, (2) the Kawang Forest Reserve in Papar, and (3) the Tawai Forest Reserve in Telupid. The three sites have different landscapes and types of forest. Table 1 shows a brief description of each of the sites.

Table 1 Brief description of study sites

No	Study site	Description
1	Tondulu Sub-Catchment Area, Tambunan (TSCA)	TSCA is a critical watershed that supplies municipal water throughout Tambunan. It is located on the eastern slope of Crocker Range Park and less than 800 m southwest of Rafflesia Forest Reserve. The area covers approximately 3, 775 ha and about 3.5 km to 8.5 km from the nearest and furthest from Tambunan town, respectively. TSCA is mainly steep hilly, and mountainous, with elevations ranging from 609 to 1, 791 m a.s.l.
2	Kawang Forest Reserve, Papar (KFR)	KFR is a Class 1 forest reserve gazetted on 24 December 2014 and is approximately 1, 551 Ha large (SFD, 2020). It is located along the Kota Kinabalu – Papar highway, approximately 30 km from the main city of Kota Kinabalu. The forest structure consists of secondary forests (69%), hills dipterocarp forests (19%), early secondary forests (8%), and field vegetation (4%) (SFD, 2013). There is a nature center located within the KFR, namely the Kawang Forest Reserve Nature Centre. This center is open for public visitation and offers a variety of activities such as hiking, environmental education programs, camping, and recreational activities.
3	Tawai Forest Reserve, Telupid (TFR)	TFR is a Class 1 forest reserve and is 22, 697 hectares large. The reserve is located in Telupid, approximately 200 km from Kota Kinabalu. It is a vital catchment area which supplies water for the whole Telupid town and features the magnificent Tawai waterfall. TFR is also home to a wide variety of flora and fauna, including the Bornean Pygmy elephant. The forest consists of ultramafic forest, upland mixed dipterocarp forest and kerangas forest.

The study is divided into two types: biodiversity studies to further understand the area's ecological integrity and, social studies to further understand the ecosystem services value through the local community's perception. Firstly, the land cover for all three sites was identified and mapped. It was then followed by the assessment of the ecological integrity of each land cover and selected biodiversity studies, including study on plant diversity, mammals and birds, anurans and fish, insects, soil and water quality, and the status of forest and other vegetation (Nilus *et al.*, 2023; Dyi *et al.*, 2023 and 2024; Lucas *et al.*, 2023 & 2024; Japir *et al.*, 2023a & 2023b; Mianus *et al.*, 2023 & 2024, Salam *et al.*, 2023 & 2024, Suis *et al.*, 2023 & 2024). Subsequently, the ecological integrity studies were assessed using indicators and pinpointed as the potential provision of ecosystem services from the study sites. For the social study, the Participatory Rural Appraisal (PRA) approach, including household survey, focus group discussion, and key informant interviews, was applied. The method for the social study is adapted from the ASEAN Swiss Partnership on Social Forestry and Climate Change

(ASFCC, 2018), whereby a sample size of 30% of households in a village (or a minimum of 40 households) was taken. The social survey helps assess the potential ecosystem services the sites provide towards the welfare of the local communities (Johnlee *et al.*, 2023 & 2024).

3.0 LAND COVER

Table 2 shows the area and percentage of each land cover in the study sites. In the TSCA, shifting agriculture has long been the foundation of land uses, livelihoods, and customs. The land cover is primarily composed of typical rural development expansion. Small parts of the forest are periodically cleared for crop development under traditional agricultural practices, and the cleared areas are then kept fallow to allow secondary vegetation to regenerate and replenish soil fertility. As the site is kept fallow for a longer period, the dispersal of climax species from adjacent old-growth forests leads to more complex secondary vegetation regrowth (Mianus *et al.*, 2023). On the other hand, a large area of KFR is forested land, approximately 64% compared to other land cover types. The forested land of KFR consists of secondary forests and advanced-growth forests. However, it was found that old-growth forests are absent, caused mainly by past disturbances due to logging activity, land clearing for agricultural purposes, and historical forest fires (Tangah *et al.*, 1998). Within KFR, there is a remnant of rubber trees from past plantations. The bare land in KFR is due to active land clearing for road development that connects the Pan Borneo Highway with the Kaiduan area. Most of the area in TFR consists of old-growth forests, secondary forests and shrubland. Furthermore, TFR faces many challenges, especially the development plans that could take some areas from TFR. It is surrounded by village settlements, restaurants, oil palm plantations, a mining area, and a centralized pig farm. Moreover, part of TFR's area is involved in the Pan Borneo highway construction and town expansion plans. The TFR is also important as it is part of the Borneo Pygmy Elephant's movement zone. Appendix 1 shows the land cover maps for TSCA, KFR, and TFR, respectively.

Table 2 Area and percentage of each land cover in the study sites

Sites Land use/ land cover	TSCA		KFR		TFR	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Old Growth Forest	2, 660.97	70.62	/	/	18,417.3	81.1
Secondary Forest	640.33	16.99	841.1	54.2	3761.78	16.6
Advance growth forest	/	/	602.8	38.9	/	/
Shrubland/ Grassland	121.01	3.21	55.2	3.6	371.16	1.6
Agricultural land	204.73	5.43	49.3	3.2	/	/
Cultivated bamboo	67.97	1.80	/	/	/	/
Barren land	23.78	0.63	2.4	0.2	69.85	0.3
River	11.21	0.30	/	/	/	/
Built up/Infrastructure	33.21	0.88	0.2	0.01	1.27	0.01
Pond	4.89	0.13	/	/	/	/
Waterbodies	/	/	0.04	0.003	75.60	0.3
TOTAL	3, 768.10	100	1551.0	100	22697.00	100

4.0 ECOSYSTEM INTEGRITY

Proponents of ecological integrity assessment methodology have consistently asserted that biodiversity is a fundamental element of ecological integrity assessment (Andreasen *et al.*, 2001; Parrish *et al.*, 2003; Willamette Partnership, 2011; Unnasch *et al.*, 2009; Faber-Langendoen *et al.* 2012a, b; Nature Serve, 2012; Vickerman & Kagan, 2014).

4.1 Biodiversity metrics

Forest ecosystems possess intricate structures and may exhibit dynamic interactions among the biota residing within and between these biotas and their physical environment (King, 1993). The biophysical structure in the

area could facilitate the establishment of numerous significant species native to the region. This is evident in high conservation value attributes, such as endemic and threatened species. The summary in Table 3 (Appendix 2) presents the number of taxa and the conservation status of species documented in TSCA, KFR, and TFR. The ecological integrity map for all sites is illustrated in Appendix 1.

4.2 Ecosystem Services

The results from the focus group discussions and the household survey indicated a diverse array of valued forest ecosystem services, with communities living in and around TSCA, KFR, and TFR recognizing the importance of ecological integrity (Johnlee *et al.*, 2023). This aligns with the understanding of ecological integrity, highlighting that forests serve as critical habitats for biodiversity and are essential for delivering various ecosystem services vital to human well-being (Brockerhoff *et al.*, 2017). Evidence is mounting that biodiversity plays a crucial role in forest ecosystem functioning and the delivery of ecosystem services. Table 3 shows the villages involved in the social study based on the respective study sites. Appendix 1 shows the maps of the provisioning, regulating and cultural service value of TSCA, KFR and TFR.

Table 3 Villages involved in the social study in TSCA, KFR and TFR

No	Study site	Villages involved (Kampung)	Number of respondents
1	TSCA	Tondulu, Kuyungon	105
2	KFR	Bisuang, Bolotikon, Tampasak, Tanaki, Kaiduan, Mook	115
3	TFR	Bauto, Gambaron, Gading, Telupid, Tapaang, Wonod, Singgahmata, Simpang Entilibon, Entilibon Asal	295
TOTAL NUMBER OF RESPONDENTS			515

Provisioning Services

Forests provide a wide array of provisioning services that directly benefit human well-being. According to Hansen *et al.* (2015), provisioning services are the products humans obtain from the ecosystem, such as food, fresh water, fiber, wood, ornamental resources, genetic resources, and medicines. The local communities living within and surrounding TSCA perceived provisioning services as the most important. Raw materials (wood, fuel wood, bamboo, rattan, and ornamentals), food (agricultural products, fish, game meat, frogs, insects, wild fruits, and vegetables), clean water, and medicinal plants were some of the recorded provisioning services that the community collected and depended on. These important sources link their well-being and their need for basic necessities to sustain their livelihoods, security, and health (Johnlee *et al.*, 2023). Water source is regarded as the most critical provisioning services of TSCA, both the municipal water supply and the gravity feed system. Similarly, for KFR, the local community regarded provisioning services as the most important. The majority of the locals rely heavily on KFR as their source of water. However, they mentioned that various land use changes, such as agricultural activities, have affected water quality. Forest resources, including timber and firewood, game meat, medicinal herbs, wild fruits and vegetables, bamboo, and rattan, were often collected to sustain their livelihood. Some even collect orchids, ferns, and nepenthes for decoration purposes. There was evidence of water pollution due to active land opening and road construction activities. The water quality assessment indicated the quality as generally clean (Mianus *et al.*, 2024). However, the detection of high fecal coliform in one of its river could pose a high risk for health issues to the community. Salam *et al.* (2024) found that *Barbodes sealei*, a Cyprinidae fish, is the most dominant species in KFR due to its preference for clear, oxygen-rich water. Along with *Gastromyzon borneensis*, the IUCN Red List lists this species as Near Threatened. Additionally, this species is presented as a bio-indicator of good water quality. (Salam *et al.*, 2024). On the other hand, for the local community in TFR, TFR is an important source of water supply. Some of the locals depended on water supply from the gravity feed water system and the municipal water supply. But it is found that the municipal water supply also obtains water from TFR. In addition, several restaurants located near TFR, are also using water from TFR to run their business. So, this shows that provisioning service is also regarded as the most important by the local community in TFR. The findings indicate that the locals do collect forest resources but only occasionally, collecting wild vegetables. This might be due to the locations of the villages which are near to the town area. However, one of the villages in TFR is threatened by a garbage dumping site located near the river which flows to their village, that led to the closing of a recreational site and pollution.

Regulating Services

Regulating services, which include a range of natural activities that support human well-being and preserve environmental balance, are essential parts of forest ecosystem services. These services, essential for maintaining healthy ecosystems, include flood control, pest management, water purification, and climate regulation. By moderating natural phenomena, such as absorbing carbon dioxide to mitigate climate change and managing water flow and soil erosion, forests play a vital role in these regulating services. Furthermore, because diverse ecosystems are more likely to be robust and effective at doing these vital tasks, the biodiversity in forests improves these services. In TSCA, the forest contributes to the effectiveness of soil retention, a major regulating ecosystem service and is important for a wide variety of human activities and related ecosystem service (Burkhard *et al.*, 2019). The soil is highly relevant in regulating water quality and climate. Water regulation is a critical ecosystem service that indirectly benefits communities' well-being by lessening adverse effects of water related disasters and extreme events through water flow regulation (MEA, 2005). The local community in TSCA experienced flood events, but no significant damage was caused (Johnlee *et al.*, 2023). For KFR, the local community reports frequent floods, landslides, mudflows, and droughts due to rubber plantations. They also mention crop diseases like termites and fungal attacks on crops and African Swine Fever, a disease affecting wild boars. Moths and butterflies are Lepidoptera's most frequently reported species, relying on them for pollination. Spiky Nest Termites, *Microcerotermes* sp., threaten trees, eating dead *Shorea* sp., and potentially destroying living ones if left unchecked. In TFR, the problems often occur are floods, river pollution, and encroachment. In addition, the opening of estates or farms from the top of the hill has polluted the village. The local community is also faced with the problem of the road to their plantation area being damaged and in poor condition, especially during the rainy season.

Cultural Services

Numerous cultural ecosystem services that forests offer improve human well-being in non-material ways. According to Brockerhoff *et al.* (2017), cultural services encompass spiritual and religious values, knowledge systems, inspiration, aesthetic values, cultural legacy, and leisure activities. Local communities have close linkages to biodiversity, forest environments, and their own cultural identities, familial ties, traditions, songs, and stories. According to Kreye *et al.* (2017), forests aid people in developing a sense of place and gratitude for the benefits they offer. Cultural services are considered important, but because they are intangible, it can be challenging to quantify their value. In TSCA, some of these values are reflected by the communities living there, including the forest ecosystem's high ecological function area (Johnlee *et al.*, 2023). The presence of significant species relevant to science, biodiversity conservation, food, and medicinal properties with educational and livelihood benefits are some of the high ecological function areas. The perceived natural setting of the montane forest landscape and historical site (e.g. salt trail) has the potential for nature recreation and ecotourism development. For KFR, a wide variety of potential tourism sites can be identified, mainly river-themed. Located along the Papar- Kota Kinabalu highway is a bonus for these sites. A notable cultural heritage is the historical stone called "Sining Dazanak." The stone is considered a remnant of ancient rituals and practices, reflecting the heritage of the indigenous communities in the region (Personal communication, July 2023). Sining Dazanak is frequently linked to spiritual beliefs and traditional customs, establishing its significance in the cultural landscape. Further research from the village's elders is necessary to uncover the whereabouts and history of this stone. Several recreational sites can also be found surrounding the TFR, offering various attractions such as waterfall, rivers, and hiking trails.

5.0 GIS APPLICATIONS

The value of ecosystem services can be effectively analyzed and represented through Geographic Information Systems (GIS), which provide powerful tools for spatially mapping and quantifying these services. GIS allows researchers and policymakers to visualize the distribution of ecosystem services across different landscapes, such as provisioning, regulating, and cultural services. By integrating spatial data with socio-economic variables, GIS can reveal service availability and usage patterns, helping to identify areas of high ecological value and those under threat. This spatial analysis facilitates informed decision-making by illustrating trade-offs and dependencies between ecosystem services and human activities, ultimately supporting sustainable management practices that enhance ecological health and community well-being (D'Auria, 2018).

6.0 RECOMMENDATION

Implementing these recommendations can enhance the provisioning services provided by forests while safeguarding the health and well-being of local communities dependent on these vital resources.

Sustainable Land-Use Practice

Including trees in agricultural systems may protect water quality, increase biodiversity, and improve soil quality. This approach can give local populations more sources of income while reducing the detrimental consequences of changing land use on water resources. Sustainable use of forest products, both wood and non-timber, needs to be practiced to protect forest resources for future generations and preserve local livelihoods.

Water Quality Management

A better understanding of the water governance system is needed to promote solutions to regulate local community activities with environmental and water policies. A reliable method needs to be implemented to monitor the water quality that local communities use regularly. This includes monitoring fecal coliform levels and other contaminants that may have an impact on human health is part of this. Surface runoff due to urban expansion and agriculture needs to be dealt with.

Community Engagement and Education

Educational programmes can be organized to educate the community about the value of sustainable practices and the possible harm that pollution may do to their livelihoods and health. The local population can be included in the development and administration of water quality and forest resources. Their knowledge may result in more sensible and efficient solutions.

Restoration Initiatives

Conduct rehabilitation of degraded areas by locating and restoring areas affected by pollution or changes in land use, emphasizing reintroduction of natural vegetation that can enhance water quality and serve as a habitat for wildlife. Biodiversity conservation by preserving important habitats for species like *Barbodes sealei*, which act as bio-indicators of water quality, is also important in assuring their survival and boosting the resilience of ecosystems.

Policy Development

To advance in environmental sustainability, it is essential to strengthen environmental laws by supporting measures that restrict detrimental land use practices, especially those that exacerbate water pollution, including unregulated agricultural expansion and developing and administering appropriate garbage disposal. The shift to more sustainable land management and resource usage can also be aided by creating financial incentives for companies and farmers that implement eco-friendly methods, such as organic farming and sustainable forestry.

Encouraging Local Stewardship of Ecosystem Services

Furthermore, encouraging local stewardship of ecosystem services can be achieved by increasing community involvement in forest management decisions. Establishing routine ecosystem service monitoring will aid in evaluating the success of management strategies and adjusting to shifting environmental circumstances. Finally, supporting biodiversity within forest ecosystems is critical because diversified ecosystems can better withstand shocks and provide crucial regulating services like managing pests, controlling flooding, and regulating climate. The essential regulating functions that forests offer can be preserved while promoting the welfare of nearby communities by incorporating these suggestions into a cogent management plan.

Integrating Cultural Ecosystem Services into Policy Frameworks

Additionally, developing ecotourism initiatives can capitalize on the aesthetic and recreational potential of forest areas, like the montane landscapes in TSCA and the river-themed sites in KFR, while respecting local traditions and heritage. Efforts should also be made to document and preserve cultural heritage sites, such as

the “Sining Dazanak” stone, which reflects indigenous practices and beliefs. Furthermore, integrating cultural ecosystem services into policy frameworks will ensure these intangible benefits are recognized and valued alongside more quantifiable services. By adopting these recommendations, forest management can support biodiversity and ecological health and the cultural identities and well-being of local communities.

7.0 CONCLUSION

The findings underscore forests' critical role in providing diverse ecosystem services that significantly contribute to human well-being. Provisioning services, such as food, clean water, and raw materials, are vital for local communities, particularly in areas like TSCA and KFR, where reliance on forest resources is pronounced. However, challenges such as land use changes and pollution threaten these essential services, highlighting the need for sustainable management practices. Regulating services, including flood control and climate regulation, further illustrate the forests' importance in maintaining ecological balance and mitigating natural disasters. Despite some communities experiencing adverse events like floods and pollution, the overall resilience of forest ecosystems remains crucial for supporting human activities. Additionally, cultural services enrich community life by fostering spiritual connections and cultural identities tied to the forest environment, although these intangible benefits are often difficult to quantify. The potential for ecotourism and recreational activities presents opportunities for economic development while preserving cultural heritage. Finally, applying GIS offers valuable insights into spatial patterns of ecosystem services, facilitating informed decision-making for sustainable management. A holistic approach that integrates provisioning, regulating, and cultural services is essential for enhancing ecological health and community resilience in forested regions.

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