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REGULAR RESEARCH ARTICLE

Mapping the Demand for Ecosystem Services in Human-Dominated Topical Forest of Sabah, Malaysia

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ABSTRACT

Mapping the demand for ecosystem services (ES) is a profoundly debated research topic that needs to be investigated further to overcome spatial discrepancies between supply and demand in the literature. This study proposes a holistic approach to valuing ES, which is demanded by local people living adjacent to Sabah's protected area in the southwestern part of Sabah, Malaysia. To assess the local people's demand for ecosystem services, we applied the 'ES Matrix Assessment' method. Timber, global climate regulation, recreation, and ecotourism are selected to illustrate the changes in ES demand patterns reported in the Klias Peninsula region. To identify the ES required by local people based on land-cover type, we used a weighted arithmetic mean approach. Then, using multiple regressions, we identified socio-demographic characteristics that influence demand for ES obtained from the Klias Peninsula's tropical forest. The 6-point Likert scale results showed that timber received medium (3) to highly relevant demand (4) among local people in the forest ecosystem, while climate regulation demand was the most highly relevant demand (5) in the forest ecosystem, and recreation and ecotourism are highly demanded in the forest ecosystem and water-based area. Overall, ethnicity, source(s) of income, distance from the protected area, length of residence, and education level have influenced the population's perception of ecosystem service demand in peat swamp forest, mangrove, and forest land, and these factors are statistically significant at the 1% to 5% levels. Our approach possesses the advantage of being intuitively straightforward, making it easy to convey to stakeholders and decision-makers across various ecosystem service (ES) applications. Therefore, our approach, while relatively simple, remains realistic and easy to apply, effectively raising awareness about the utility of the ecosystem services concept for stakeholders and policymakers.

KEYWORDS
Ecosystem Management; Ecosystem Services Indicators; Ecosystem Services Social Demand; Socio-demographic Factors; Wetland Ecosystem.

1. INTRODUCTION

The mapping of ecosystem services (ES) is vital for land-use planning. However, the application of a standardised approach to quantifying ES is still subject to debate, as it should entail ecosystem-based management strategies (Bai et al., 2018; Hasan et al., 2020). In the last decades, mapping the demand for ES has received increasing attention in scientific research (Wei et al., 2017; Wolff et al., 2015; Xu et al., 2022). Nevertheless, research on the demand for ES is underrepresented (Burkhard et al., 2014; Feng et al., 2021; Honey-Rosés & Pendleton, 2013; Wei et al., 2017). Wolff et al. (2015) identified a mere 31 studies conducted on this topic, the majority of which focused on European countries. In addition, numerous studies have developed a promising method for assessing the demand for ES (Liu et al., 2023; Schulp et al., 2014; Schwartz et al., 2021; Stürck et al., 2014; Zhang et al., 2021).

However, as conveyed by Wolff et al. (2015), there is no mutual agreement among the scientific community on the concept of ES demand. This controversy has repercussions for the mapping of ES demand. We identified categories corresponding to the demand for ES: consumption of goods and services, preferences and values, and direct use of resources or risk reduction. Burkhard et al. (Burkhard et al., 2012, 2014) were the first to initiate measuring the holistic demand for ES. Burkhard equated the demand with the actual use or consumption of goods and services. The use of ES relates to the final commodities from which benefits are obtained under the current supply of ES. The issue of including this nomenclature in the task of mapping the demands obscures the presentation of certain stakeholders' demands for ES. Instead of articulating the demands, all of the ecosystem goods and services describe what is currently consumed or used in a particular area over a given time period (Campagne et al., 2020). Exposing the ecosystem's potential to sustain human existence has subjected natural resources to further exploitation as a consequence of human demands (Lampert, 2019). Wang et al. (2020) and Schirpke et al. (2021) further elaborated on the concept of demand. Both authors applied the socio-economic characteristics of desire and preference to the definition of demand for ES. Desires and preferences motivate human behaviour to use and consume goods and services offered by their surroundings (Lhoest et al., 2020; Wolff et al., 2015). However, these definitions do not provide a clear indication of where the demand for ES should be mapped. If demand assessment is based on individual desires and preferences, the assessment includes the goods and services required for personal well-being and quality of life (Costanza et al., 2007; de Groot et al., 2012). This creates substantial consequences and strongly impairs the results of the mapping of the demand for ES.

The mapping of the demand for ES is based on different concepts capable of imparting different insights. However, to improve the indicator quality and policy relevance of maps displaying the demand for ES, a mutual understanding of the concept, and robust, credible, and accurate indicators of the assessment are required (Campagne et al., 2020; Schulp et al., 2014; Vallecillo et al., 2019). In any case, to assess the ES demand, the respective stakeholders, and the driving forces behind them, we need to understand the respective socio-ecological system (Braat & de Groot, 2012; Jo et al., 2021; Lyu et al., 2019). The socio-ecological system has been defined as (a) a coherent system of biophysical and social factors that regularly interact in a resilient, sustained manner; (b) a system that is defined at several spatial, temporal, and organisational scales, which may be hierarchically linked; (c) a set of critical resources (natural, socio-economic, and cultural) whose flow and use is regulated by a combination of ecological and social systems; and (d) a perpetually dynamic, complex system with continuous adaptation (González De Molina & Lopez-Garcia, 2021; Machlis et al., 1997; Tasca et al., 2020).

Therefore, in this study, we applied the definition proposed by Albert et al. (2016), which defines 'demand' as follows: 'the need for specific ES by society, particular stakeholder groups, or individuals. ES demand is specific in time and space, with some demand existing globally and other demand existing locally. ES demand can be higher than ES flow. Other ecosystems need to be imported if demand exceeds flow in a region' (p. 40). We suggested using Albert et al. (2016) affirmative term "ES demand" in this research because it provides relevant information on providing planning for policy decisions. The relevant political information should include the spatial areas where disproportionate supply and demand exist. The areas in which the greatest welfare gains could be generated by enhancing the quality of ES delivery through proper management should also be included.

Tropical forests support the greatest biodiversity in the world's ecosystems. Tropical forests cover approximately 0.7% of the world's land surface, and the majority of such forests are located in Southeast Asia (Hoang & Kanemoto, 2021), where most of the "hot spots" and endemic species are discovered. However, overexploitation and land clearing for the purpose of commercial agriculture during the nineteenth and twentieth centuries (de Bivar Marquese, 2022) have resulted in a significant decline in the total tropical forest cover from 268 Mha in 1990 to 236 Mha in 2010 (Kenea et al., 2020). Heavy losses of high-biodiversity habitats have greatly accelerated recently in Southeast Asian countries. The increasing demands of rapidly growing populations have substantially contributed to changes in land use, especially in developing countries. The conversion of forest land has largely benefited the oil palm plantations and has caused a greater threat to the tropical forest (Namkhan et al., 2020). Nonetheless, the land continues to be exploited due to the crucial resources it offers for sustaining livelihoods. Therefore, in order to confront the threat of forest fragmentation, prevent the extinction of endemic species, and conserve the ecological integrity of forests, a significant attempt was made to gazette larger parts of the land as protected areas. The general trends were to protect areas from the exploitation of the corresponding ES and to reduce land conversion. However, this may result in attempting to protect the forest while simultaneously generating enough food to satisfy human demands. Thus, the Millennium Ecosystem Assessment introduced the concept of ES into global environmental policy (Reid, 2005). The concept interconnects the discourse between biodiversity conservation and sustainable development to encourage conservation of resources and land use by considering both ecological and social aspects (van Noordwijk, 2021; Wang et al., 2020; Wei et al., 2017).

Ecosystems provide multiple services that are reliant on biodiversity and ecosystem functioning, and are necessary for the well-being of humankind. Mapping, monitoring, and balancing the supply of ES is vital to supporting decision-making with respect to the management of sustainable natural resources (Campagne et al., 2020; Crossman et al., 2013; Schwartz et al., 2021; Wolff et al., 2015). However, the majority of studies on ES demand focus on continental European countries (Albert et al., 2016; Stürck et al., 2014; Wolff et al., 2015). A few studies on ES demand focused on an area outside of Europe (Campagne et al., 2020; F. Li et al., 2020; Shaad et al., 2022; Wei et al., 2017): but the conditions of this study were not comparable to Malaysia. Demand assessments, with particular attention to protected forest areas in Malaysia, are either absent or inadequate. Therefore, this study aimed to compensate for the missing information on multiple ES assessments and mapping on a landscape scale in the tropical forests of Southeast Asia. Thus, after completing an analysis of changes in the land cover and in the respective ES sourced by a protected peat swamp forest area in Klias Peninsula of Sabah, Malaysia (Bürger-Arndt et al., 2016; Kamlun et al., 2016; Kamlun & Bürger Arndt, 2016, 2019), the main purpose of the present study was to identify local communities' preferences for the relevant ES demand indicators, the demanded services, and how the services have changed through time. The authors tried to understand the changes in the demanded ES over the past 28 years and further aimed to integrate the socio-ecological characteristics that influenced the locals' demand for the tropical forest ecosystem. At the same time, the identified demand indicators can be applied for further similar studies in other regions with a similar ecosystem setup, such as Malaysia and other tropical countries. The pursuit of these objectives was guided by Bürger-Arndt (Bürger-Arndt et al., 2016) and Kamlun and Bürger-Arndt's (2016) proposed conceptual framework of relevant human-forest interrelations for assessing forest ES.

2. MATERIALS AND METHODS

2.1 Study area

This study was conducted on the Klias Peninsula of Sabah, East Malaysia (Figure 1). The area covers two rural districts of Sabah: Beaufort and Kuala Penyu. Klias Peninsula consists of extensive wetlands covering the northwest of Kuala Penyu and the whole of southern Beaufort. At 1707 km2, the Beaufort district is the largest area, while Kuala Penyu is 448 km2. Most of the land is situated in the coastal zone (>60%), with the remaining areas found in the highlands. As depicted in Figure 1, the terrain is predominantly flat, with elevations ranging from 0 to 10 metres above sea level. Agriculture, particularly oil palm and rubber plantations, is the area's main economic activity, and most of the local population depends on subsistence agriculture and fishing. The major land covered is agriculture and forestry, whereas the urbanised area is relatively small, as is the case in most of the rural districts in Sabah. The forest reserve comprises 39,060 hectares, covering more than 22% of the total area. Consequently, more than 70% of the area is not designated as a protected area, including the alienated lands and state lands.

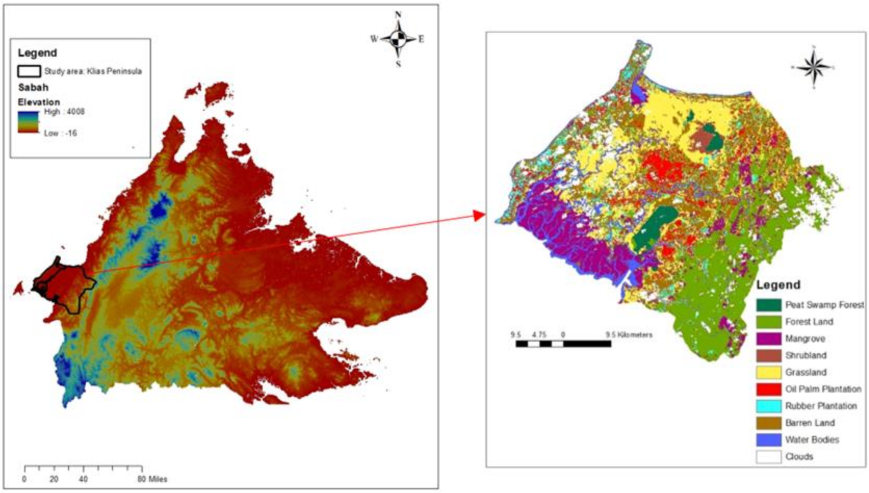

Figure 1. Location of Klias Peninsula, Malaysia, in Borneo Island. Right map: Land Cover Classification in 2013 (Kamlun et al., 2016)

As one of the few remaining peats swamp forests in Sabah, Klias Peninsula has been acknowledged as one of the most important ecosystems to conserve. The management and conservation initiative were established by the Malaysian Government, together with the United Nations Development Program (UNDP) and the Global Environment Facility (GEF), to ensure the conservation and sustainable use of the peat swamp forest resources in this area. The peat swamp forest ecosystem has subsided dramatically as human populations have increased, causing a heightened consumption of resources. The Klias Peninsula area endured multiple forest fires over the course of the El-Niño event. The first reports of such massive fires in the area occurred in 1997, with the most recent incident documented in 2010 (Kamlun et al., 2016; Osman et al., 2012). In the early 1980s, the peat swamp forest in Sabah was reported to comprise 86,000 hectares, and 60,000 hectares of mixed peat swamp forests were located on the Klias Peninsula (UNDP/GEF, 2006). Two major forest reserves in this area have been established as protected areas in an effort to safeguard the remaining peat swamp forest. The areas, namely Klias Forest Reserve (3620 hectares) and Binsuluk Forest Reserve (12,106 hectares) (Kamlun & Phua, 2024), were classified as Class 1 protected areas in 1984. A Class 1 protected forest is conserved primarily for environmental protection and biodiversity conservation. These forests are legally shielded from any form of land conversion or timber exploitation. Currently, the remaining peat swamp forest in Klias Peninsula is estimated to be less than 40,000 hectares. According to the estimation corroborated by Kamlun (2016), the annual rate of change in the protected area is 10.94% (±0.85% margin of error) per year for deforestation and 0.86% (±5.19% margin of error) per year for losses in the forest area. This result indicates that a significant portion of the peat swamp forest has been converted to stable non-forest areas, including agricultural plantations, posing a threat to the already-disturbed protected area.

Furthermore, there are numerous villages located adjacent to the protected area that have encroached on the nearby boundaries. This issue heightens the threat of forest fires during the dry season. One of the causes of encroachment is the implementation of the agricultural expansion policy, leading to the alienation of state land in most areas bordering the protected area. The intrusion of communities occurred in the northern part (Binsuluk Forest Reserve) of the area. Following the 1998 forest fire event, the Binsuluk Forest Reserve reported that more than 70% of the peat swamp forest was damaged and highly degraded. In relation to the degradation issue, there is increasing pressure for the forest area to be converted to other types of land use. In the study area, land applications are not processed systematically according to land capability. This exacerbates harm to the existing protected area, impeding the preservation of the forest's ecosystem and the sustainability of local communities.

2.2 Identification of the relevant indicators for the ES demand assessment

A wide range of explicit subservices has been identified and utilized by various researchers within the categories of provisioning services, regulating services, and cultural services (Crossman et al., 2013; Krasny et al., 2014; Müller & Burkhard, 2012). Constructing a clear, meaningful, and acceptable classification system for assessing ecosystem services (ES) in the decision-making context is crucial to developing relevant services. This entails applying a broad spectrum of processes that interconnect with social choices, ranging from information gathering to communication processes, thorough analyses, and implementation based on actual assessments. Using an inappropriate classification of subservices can lead to problems concerning consequential and robust outcomes (Fisher et al., 2014).

In terms of our selection for provisioning, regulating, and cultural services, we adopted the classifications introduced by the “ES pioneers" (Costanza et al., 1997; Daily, 1997; Reid, 2005). Subsequently, we transcribed the interviews conducted in local communities to extract relevant indicators of ES demand for local application. For the interviews, we created a theme for each category to exemplify and illustrate the related structured interview content, which was divided into two main issues: potential demand indicators for each service and the beneficiaries (end users). To obtain comprehensive indicators, we followed the methodology outlined by Müller and Burkhard (Burkhard et al., 2014; Müller & Burkhard, 2012), as illustrated in Figure 2.

The identification and characterization of ecosystem services (ES) demand indicators are performed by local people. To ensure accurate information for determining the feasible use of land planning, indicators for mapping the demand for ES must be developed. However, there are few trustworthy indications for such a comprehensive assessment (Burkhard et al., 2014; Wolff et al., 2015; Xu et al., 2022). Consequently, there is a growing interest in generating metrics for ES. Müller (Felix et al., 2011; Müller & Burkhard, 2012) suggested quantifying ecosystem sub-services and ecological functionality by using a holistic collection of indicators to determine ES. Similarly, a collection of demand indicators must be expanded to include ES provided by coastal and marine environments, as well as a broader spectrum of cultural ES offered by a diverse range of institutions.

For this reason, we identified and collected a considerable number of indicators through thematic analysis, literature extraction (Kamlun & Bürger Arndt, 2019) , and semi-structured interviews conducted within the villages located on the Klias Peninsula. We developed sets of potential indicators that can be used to assess the demand for each sub-service. Finally, we combined all pertinent variables with data gathered from interviews and qualitative literature review assessments in our local area.

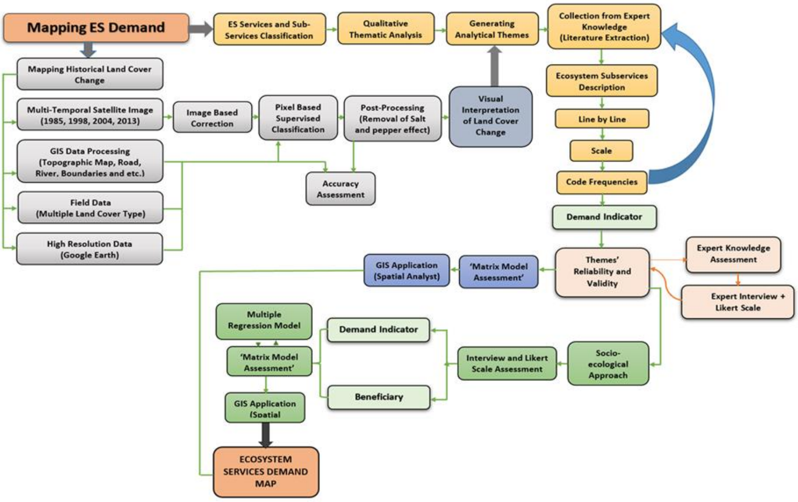

Figure 2. Workflow on quantifying ecosystem services demand in Klias Peninsula.

2.3 Identification of the relevant indicators for the ES demand assessment

We created a multi-temporal land cover change map of Klias Peninsula between 1985 and 2013 as the first stage in an ecosystem services (ES) demand assessment (Kamlun et al., 2016; Kamlun & Bürger Arndt, 2019). We used Landsat satellite images acquired from the United States Geological Survey (USGS) (Path/Row: 118/56). All images to facilitate time series analysis in this study are detailed in Table 1. The nine land-cover classes applied to the study area are: (1) peat swamp forest; (2) forest land; (3) mangrove; (4) shrubland; (5) grassland; (6) oil palm plantation; (7) rubber plantation; (8) barren land; and (9) water bodies. The outcome of this mapping assessment is presented in Kamlun et al. (2016) .

Table 1. Satellite image information for data acquisition applied in this study.

Imagery date	Spatial resolution	Satellite/sensor	No. of bands
June 29, 1985	60m	Landsat-5 (MSS)	4
November 24, 1998	30m	Landsat-5 (TM)	7
June 17, 2004	30m	Landsat-5 (TM)	7
April 23, 2013	30m (Except Band 8 Panchromatic: 15m)	Landsat-8 (OLI_TIRS)	9

The Department of Survey and Mapping Malaysia provides us with a land-use map. This land-use map was used to identify the villages in the vicinity of two main protected forest areas (Binsuluk Forest Reserve and Klias Forest Reserve). Using concentric circle sampling, we identified the villages for the survey assessment by Meijaard (2013). For this purpose, we mapped the boundaries of the forest reserves and the village localities using a Geographic Information System (ArcGIS 10.1). We selected 10 villages at a distance of less than 2000 metres as a sample for the assessment. We calculated concentric circles (buffers) of 500, 1000, and 1500 metres from both protected areas using a buffer tool. Four-distance buffers were employed to account for the adjacent land-cover types around the nearby communities.

In these sampled villages, we conducted semi-structured interviews using a Likert scale-type questionnaire with a sample of 281 respondents from May to August 2015 through non-probability sampling for convenience. The aggregated respondents represented more than 30% of the total population in each village. We matched local people's demands and preferences for various ecosystem services to the most appropriate land cover types, derived from the findings of our past investigations (Chen et al., 2021; Kamlun et al., 2016; Kamlun & Bürger Arndt, 2019). We focused on the ES that were in the highest demand in the local communities, i.e., based on what was the most crucial to sustaining livelihood and land use according to local inhabitants. To represent these perspectives, we excluded the demanded services that are provided by sources located outside of the assessed area.

We used Burkhard's technique to map ES demand and supply previously (Burkhard et al., 2010, 2012, 2014). Burkhard developed a non-monetary evaluation concept of a broad range of ES supply and demand. In both cases, the approach uses ES subtypes, which are plotted on the x-axis, and different land-cover/ land-use types, which are presented on the y-axis. Next, a qualitative and further semi-quantitative matrix assessment was performed with respect to the capability of the different land cover/ land-use types, scientific or expert knowledge, and considering the human demands (expectations) that are present in each area. This approach to assessing ES demand was also used with respect to people's expectations for specific land cover types, even considering different stakeholders and actors. One of the strengths of the ES matrix approach is its highly flexible and adaptable approach to assessing and mapping ES, based on various data sources with different study area settings from local to national (Campagne et al., 2020; Jo et al., 2021).

In our study, we asked for the ES demands of local residents and representatives in the selected villages. As explained by Bastian (2013), we focused on the spatial distribution of the demand for services with consideration of knowledge provided by informants living in the respective land-cover types. Consequently, demands are accentuated where population sizes are greater in urbanised areas, which, by contrast, can barely accommodate these needs; as a result, populations depend on their rural surroundings (sink) to supply the required services (sources). City planners or politicians might find it worthwhile to illustrate or map this outcome, for example, in the context of reducing emissions from deforestation and forest degradation (REDD) or the payment of ecosystem services (PES). For this purpose, the Likert scale type of matrix values (0–5) was used. This paper was classified into three groups: the demand for provisioning services, regulating services, and cultural services. The scale values and colour coding method indicated the following demand: 0 (rosy) for no relevant demand from local people (within the particular land-cover type for the respective ES concerning the particular land-cover type); 1 (dark-rosy) for low relevant demand; 2 (light-red) for relevant demand; 3 (red) for medium relevant demand; 4 (dark-red) for high relevant demand; and 5 (brown-red) for very high relevant demand for each subservice. To calculate the Likert scale value to represent the local people's preferences, we incorporated a weighted arithmetic mean calculation. Instead of each data point contributing equally to the final mean, some data points contributed more "weight" than others. If all the weights are equal, then the weighted mean equals the arithmetic mean. The technical formula for the weighted arithmetic mean is represented below:

$$\frac{\bar{X}\sum wx}{\sum x} \qquad \text{Equation (1)}$$

Where, X= the weighted average, Σ = the sum of all the Likert values demanded by the local community, w = the weights for each data point, and x = the values of each data point.

Finally, the visual interpretation provided by maps, depicts how the local people's demand preferences for ES have changed over 28 years (1985–2013). Recreation and eco-tourism, as well as timber and global climate regulation, are included to exemplify the changes in demand patterns documented on the Klias Peninsula.

2.4 Socio-demographic factors undermining the factor influencing demand of ES

We then explained the possible factors that might affect ES near the protected area by using a multiple regression statistical model. The supply of ES can be affected by numerous drivers of change that can be divided into the categories of direct (e.g., harvesting, land-coverchange) and indirect (e.g., cultural or religious issues, economic change, climate change). Among the human-induced indirect drivers, economic conditions have been highlighted as the ~~most sig~~nificant factors that induce changes in land cover (Chu et al., 2019).

We used a multiple regression statistical model to explain the relationship between different ES of provisioning, regulatory, and cultural services and socio-demographic factors that affect local populations, which were proposed by Meijaard (2013) and Ladau and Averitt (2004): The model is defined as:

$$Y_t = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \varepsilon_t \qquad \text{Equation (2)}$$

Where Table 2 represents the description of the variables used in the model:

Table 2. Variable description for multiple regression statistical model

	Label	Description
Y_t	Dependent variables	Provisioning or Regulating or Cultural Services
α	Constant	
β	Coefficients	β_1 +......+ β_{10} are the model parameters/ coefficients to be estimated
X_1	The nearest village from the protected area	Dummy variable (0= less than 1000 meter from the protected area, 1= more than 1000 meter from the protected area)
X_2	Gender	Dummy variable (0= male, 1=female)
X_3	Age	Years
X_4	Ethnicity	1=Melayu, 2=Cina, 3=India, 4=Murut, 5= Brunei, 6=Bisaya, 7=Kadazan/Dusun, 8= Bajau, 9= Kadayan, 10= Others
X_5	Religion	1= Islam, 2= Christian, 3= Buddha, 4= Hindu, 5= Others
X_6	Source of income	Dummy variable (0=farmers,1=non-farmers)
X_7	Household size (hh)	1= 1-2 hh, 2=3-4 hh, 3=5-6 hh, 4= 6-7 hh, 5= 8-9 hh, 6= 10 hh and above

	Label	Description
X_8	Education level	1= No formal education, 2= Primary education, 3= Lower secondary education, 4= Upper secondary education, 5=post-secondary tertiary education, 6= First stage of tertiary education, 7= Second stage of tertiary education
X_9	Residential status	Dummy variable (0=resident, 1=non-resident)
X_{10}	Period of residence	Years
ε_t	Error term	Measure variation in either Provisioning, Regulating or Cultural Services unaccounted for by the independent variables.

In this model, the provisioning services (Y1) describe the material or energy outputs from the ecosystems (Costanza et al., 1997), represented by food, water, wood, and other natural resources. For the equation, we selected essential resources such as timber, crops, fodder, livestock, wild food, capture fisheries, fuel wood, aquaculture products, medicinal resources, energy resources, freshwater resources, and genetic resources; all resources were selected additionally with respect to their relevance in the Beaufort area. Concerning regulatory services (Y2), such as air and soil quality, as well as flood and disease control (Kamlun & Phua, 2024), we first reviewed the relevant literature, as specified in the methodology (Section 2.2), before deciding on the five most relevant services provided by our study area (climate, nutrient, water and erosion regulation, and flood protection) and finalising the appropriate sub-service indicators using a qualitative and quantitative approach. Cultural services (Y3) are defined as intangibles, or nonmaterial benefits, that people can obtain from ecosystems. Spiritual enrichment, cognitive development, opportunities for reflection, recreational activities, and aesthetic experiences are all examples of cultural services. Five cultural services were evaluated in our study: recreational activities and ecotourism; cultural heritage; cultural inspiration; spiritual inspiration; and educational and scientific uses.

We first derived a new variable from each sub-category of ES to represent each land-cover type (forestland, shrubland, peat swamp forest, mangrove, grassland, rubber plantation, oil palm plantation, barren land, and water bodies). The selected variables were then organised into three main categories of ES: provisioning, regulating, and cultural services. However, in this equation, we only extracted information regarding the forest area (peat swamp forest, mangrove, and forest land).

This approach allowed us to determine the most significant factors influencing the ES available in the protected area. However, this method also has its flaws. While the selected dependent variables are reliant on indicators for ES with previously applied benchmarks, identifying suitable indicator values without having any previous experience distinguishing ‘low’ and ‘high’ performance can be rather subjective in terms of developing the equation. Considering this flaw, we assigned the same weight to all ES indicators and used simple averages to perform the regression analysis (Landau & Everitt, 2004). It could be argued that the demand for ES might differ due to individual perceptions; some may be in extremely high demand or more important than average, and others may be smaller than average. Therefore, the use of the same weight for each resource in our calculations may be misleading. However, some services essential to human existence can also be undervalued due to a lack of awareness or limited visibility and overvalued if they do not have market value (Thuy et al., 2022). While we do acknowledge these weaknesses, multiple regression nonetheless has the advantage of being intuitively clear, reasonable, and flexible. The analysis explicitly checks for the many explanatory variables that might affect the dependent variables simultaneously. Since the multiple regression analysis can accommodate many independent variables that seem to explain Y, we can create better models for predicting dependent variables and deduce causalities. An additional advantage is that it can create fairly general functional-form relationships, i.e., linear relationships. Hence, the use of multiple regression models is appropriate for determining the main drivers or significant factors that affect the demand for ES.

Our regression model also examines the impact of both quantitative variables (such as age, household size, ethnicity, and years of resident) and qualitative variables (such as gender, the nearest village from the protected area, source of income and residential status) on the dependent variables (Y1- Y3). A dummy variable is used to indicate the presence or absence of a categorical effect that is expected to influence the outcome or the dependent variable. It also serves as numerical representations for qualitative variables in a regression model. In addition, dummy variables serve as tools for categorizing data into distinct and non-overlapping categories, such as resident and non-resident. A dummy variable can be defined as a binary variable that represents a true value numerically, with 0 indicating false and 1 indicating true. A binary independent variable that takes a value of 0 for certain observations will have no effect on the dependent variable's coefficient. However, when the binary variable takes a value of 1, its coefficient will modify the intercept. The determinants of the Provisioning or Regulating or Cultural Services are therefore contingent upon the specified explanatory or independent variables that characterize ES demand for tropical forests in the study area. The SPSS software program is utilized for estimating the multiple regression of the parameters of Equation 2.

3. RESULTS AND DISCUSSION

3.1 Local people's identification and characterization of ES demand indicators

The list of ES demand indicators and the beneficiary (end user) for the demanded subservices are provided in Tables 3-5. The respective indicator representing each subservice was based on the local population's need for that service in Klias Peninsula. For example, in the context of food consumption or retail in Table 3, each subservices indicator exhibits a maximum demand amount for each service type, supported by either kg/month, kg/ha/month, tan/ha/month, RM/tan/ha/month, or RM/kg/ha/month. This refers to the indicators presented by Burkhard (2014). According to these findings, most of the suggested demand indicators do not distinguish between ES demand (consumption rates) and actual human needs. One example presented the average crop consumption in kg or kJ per person per year for provisioning services. For wild food, the local people in Klias expressed that the relevant indicator is the maximum demand harvested for retailing or consumption by bunch/week, kg/week, kg/month, number of wild food/month, or RM/kg/month that goes to either the local communities or food industries as the end user (beneficiaries). According to Thu Thuy et al. (Thuy et al., 2022), wild foods contribute to food security because they can be sold and provide cash income for households and individuals, where they play an important role in providing safety nets to buy other foods. Distinct from Vári et al. (2020), where the amounts per species are used as an indicator for mapping wild plants as an ES in Transylvania. For freshwater supply, maximum demand for water consumption is represented as the amount of gallon per week, gallon per month, litter per month, litter per third month, or RM per month. Various indicators were presented for fresh water supply, as there are several water resources in the Sabah rural area besides treated water supply, such as river water, rainwater, and groundwater through manually dug wells (Nainar et al., 2022; Sarbatly et al., 2023).

In the list of regulation services indicators developed in Table 4, we proposed the indicators for climate regulations as the maximum demand for heat regulation. We defined as kWh/month the amount of heat prevented (e.g., fan use, air conditioning) to regulate the climate. According to Lüttge and Buckeridge (2020), climate and air regulation are very important for human well-being because of the role each service plays in mitigating temperature-induced stress. Sabah, Malaysia, endures the El-Nino phenomenon on an annual basis. This phenomenon causes not only forest fires to occur every year on the Klias Peninsula but also extreme air pollution (Chew et al., 2022; Kamlun et al., 2016). Temperature patterns are strongly connected to reducing the negative effects experienced by the production of heat on islands (Gill et al., 2007; Rahaman et al., 2022), and to improving air quality (Baumgardner et al., 2012; Larondelle et al., 2014; Sahani et al., 2021). Furthermore, trees and wetlands reduce local air pollutants by absorbing the toxins from the polluted air (Biswal et al., 2022; Bolund & Hunhammar, 1999), mitigating heat waves by evaporation through tree covers (Bowler et al., 2010; Kubilay et al., 2020) and reducing extreme weather events (Costanza & Kubiszewski, 2012; Prouty et al., 2020). However, global demand for energy consumption from cooling has increased the use of cooling appliances in the tropics, which is adequate for cooling and improves indoor environmental quality due to the heat (Miller et al., 2021).

Furthermore, according to the local scale assessment, nutrient regulation sub-services are presented as being in maximum demand for fertiliser consumption and types of trees planted as indicators. However, there are unintended consequences of human intrusions on ecosystems, specifically the undesirable decline in other types of ES. According to Tanaka (2021), agriculture has a profound effect on biogeochemical cycles and the supply of nutrients found in ecosystems. The nutrients required for agricultural ecosystems are nitrogen and phosphorus. Nitrogen and phosphorus fertilisers have greatly increased the amount of new nitrogen and phosphorus present in the biosphere and have had complex, often harmful, effects on natural ecosystems (Vitousek et al., 2009; Wen et al., 2022). The high volume of fertilizer-mobilized nutrients that enter both groundwater and surface water has had many negative consequences for human health and the environment (Dutta Gupta et al., 2018; Power, 2010). To represent flood protection and erosion regulation sub-services, 'maximum demand' in relation to the total number of prevented disasters was included based on the semi-structured interview information obtained from local interviewees. Klias Peninsula experiences regular floods, which have worsened over time. The conversion of the peat swamp forest to other land-cover types caused the flooding. The local community expressed a high demand for flood prevention. The solution proposed by the local community is to expand the river opening near the affected village area. The local interviewees further explained that a highland area is necessary for the purpose of relocating the locals from flood-affected areas.

Table 3. Key ecosystem subservices identified in the study area for provisioning: descriptions, relevant demand indicators and beneficiaries (end user)

Ecosystem sub-services	Descriptions	Relevant demand indicators	Beneficiary (end user)
Provisioning services			
Crop	Presence of cultivation of edible plants. Materials that can be consumed for energy and nutrition. Used for livelihood support.	Maximum demand on crop production retailing or for consumption (kg/month; kg/ha/month; tan/ha/month; RM/tan/ha/month; RM/kg/ha/month)	Agriculture trader, Malaysian Palm Oil Board (MPOB),

Ecosystem sub-services	Descriptions	Relevant demand indicators	Beneficiary (end user)
			rubber industry board, local traders
Livestock	Presence of keeping edible animals. Materials that can be consumed for energy and nutrition. Used for livelihood support.	Maximum demand on livestock production retailing or for consumption (kg/month, kg/ha/month, RM/kg, RM/kg/ha/month, No. of livestock (n)/ha/ biannual, types of livestock)	Local and regional communities, livestock traders, poultry company
Fodder	Presence of cultivation and harvest for animal food and consumption. Materials that can be consumed for energy and nutrition by animals.	Maximum demand on fodder production (kg/ha/month)	Local communities
Capture fisheries	Presence and catch of commercially interesting fish species, which are accessible for fishermen. Materials that can be consumed for energy and nutrition. Used for livelihood support.	Maximum demand on fish capture for retailing or for consumption (kg/month, kg/ week, number of fish (n)/week, tan/month, RM/kg/ month)	Local or regional communities, fish trader
Aquaculture products	Presence of animals kept in terrestrial or marine aquaculture. Materials that can be consumed for energy and nutrition. Used for livelihood support.	Maximum demand on seafood harvested for retailing or consumption (kg/month, kg/ha/month, RM/kg/ha/ month, number of fish type (n)/ month)	Local or regional communities, fish trader
Wild foods	Presence and harvest of, e.g. mushrooms, vegetable or wild animal hunting. Materials that can be consumed for energy and nutrition. Used for livelihood support.	Maximum demand on wild food harvested for retailing or consumption (bunch/week, kg/week, kg/month, no. of wild food (n)/ month, RM/kg/ month	Local communities, food industry
Timber	Presence of trees or plants with potential use for timber. Used for livelihood support.	Maximum demand on harvested wood (bunch/ month, m^3/ year, trees stand/ year, m3/y ear, type of trees, number of trees, timber function)	Local communities, local traders
Fuel Wood	Presence of trees or plants with potential use as fuel.	Maximum demand on harvested wood (bunch/ week, bunch/month, m^3/week, m^3/ month)	Local communities, family
Energy supply	Biomass that uses for other purposes other than food. Presence of trees or	Maximum demand on energy resources (RM/litter/month, litter/ month, fuel gas	Oil company, state electricity supply

Ecosystem sub-services	Descriptions	Relevant demand indicators	Beneficiary (end user)
	plants with potential use as energy source.	consumption, RM/month, kWh/month)	
Medicinal resources	Natural materials with potential use to maintain, restore or improve health	Maximum demand on substances used for medicinal purpose (Type of medicinal plant extracted; kg/month)	Local communities
Genetic resources	Measurable at species, molecular and sub molecular levels. Presence of species with (potentially) useful genetic material	No data	No data
Fresh water supply	The role of ecosystems in providing water through sediment trapping, infiltration, dissolution, precipitation and diffusion. Presence of freshwater and water reservoirs	Maximum demand on water consumption (gallon/week, gallon/ month, litter/month litter/3 month, RM/month)	Local communities, state water supply

To date, the issue undermining cultural ES is that no adequate indicators have been developed for its assessment (Cheng et al., 2019; Schröter et al., 2021). The majority of the ES focuses exclusively on developing the indicators for provisioning services. Cultural services are mainly developed based on where a person is needed who perceives the ‘aesthetic, cultural, and inspirational values of the landscape or nature’ and primarily relate to the subservices of ‘recreation and ecotourism' (Czúcz et al., 2018, 2020; Maes et al., 2013). This further demonstrates that the assessments for cultural services are rather disregarded, which is why a list of potential indicators for the assessment of cultural services has been described in depth in Table 5. The indicators of cultural services focus predominantly on the services in maximum demand, the local community’s preferences for the number of local facilities, and the potential types of activities available. These indicators represent the sub-services related to recreation and ecotourism, as well as educational and scientific interests. Hernández-Morcillo (2013) stated that the classification of cultural ES indicators is determined by the respective area’s physical, chemical, and biological properties. Furthermore, we contend that the properties of the ecosystem and the accessibility of the ecosystem’s specific services should link the indicators together. In contrast, in this study, the cultural subservices indicators (cultural heritage, inspiration for culture, and spiritual inspiration) mainly describe the maximum demand for the number of specific landmarks, items, and elements representing each subservice. The Millennium Ecosystem Assessment defines ‘inspirational values’ as ‘values providing a rich source of inspiration for art, folklore, national symbols, architecture, and advertising’ (UNEP-WCMC, 2010). As for Jaworek-Jakubska et al. (2020), the authors assert that potential indicators for visual landscape characteristics should include spectacular, unique, or iconic elements, landmarks, and historic elements and patterns, which in this study present a similar outcome.

Table 4. Key ecosystem subservices identified in the study area for regulating: descriptions, relevant demand indicators, and beneficiaries (end users).

Ecosystem sub-services	Descriptions	Relevant demand indicators	Beneficiary (end user)
Regulating services			
Climate regulation	Influence of ecosystem on local and global climate through land cover and biologically-mediated processes that regulate atmospheric processes and weather patterns. Changes in land cover can affect temperature, wind, radiation and precipitation.	Maximum demand on heat regulation (kWh/month, number of prevented heat e.g. fan use, air conditioning)	Oil company, state electricity supply
Nutrient regulation	The role of ecosystem in the transport, storage and recycling of nutrients. The capacity of ecosystems to carry out (re)cycling of, e.g. N, P or others	Maximum demand on fertilizer consumption (kg/ha/year), type of trees planted	Agricultural areas, local communities fertilizer supplier
Flood protection	Role of forests and natural elements dampening extreme events (e.g. protection against flood damage). The soil profile stores water and reduce runoff.	Maximum demand on total number of prevented flood	Local communities
Air quality regulation	The capacity of ecosystems to remove and extract aerosols, chemicals, toxic and other elements from the atmosphere	Maximum demand on type of tree planted, total number of tree planted	Local communities
Erosion regulation	Vegetative cover plays an important role in soil retention and the prevention of landslides. Minimizing soil loss through having adequate vegetation cover, root biomass and soil biota	Maximum demand on total number of prevented erosion	Local communities

Table 5. Key ecosystem subservices identified in the study area for cultural: descriptions, relevant demand indicators beneficiaries (end user).

Ecosystem sub-services	Descriptions	Relevant demand indicators	Beneficiary (end user)
Cultural services			
Recreation and ecotourism	Refers specifically to landscape and visual qualities of the respective case study area (scenery, scenic beauty). The benefit is the sense of beauty people get from looking at the landscape and related recreational benefits. Landscape-features attractive wildlife; important landscape features or species. Recreational motivation provided by	Maximum demand on the number of facility, number of potential recreation and ecotourism activity (RM/month, RM/year, number of nature and leisure preferences, sightseeing, wildlife viewing, cultures)	Local and regional communities, local and international visitors, local and international tourist, family

Ecosystem sub-services	Descriptions	Relevant demand indicators	Beneficiary (end user)
	extent and variety of natural features and landscapes.		
Cultural heritage	Aesthetic quality of the landscape, based on e.g. structural diversity, 'greenness', tranquillity. The inspiration and motivation, historical and aesthetic values; health enhancement; sense of place; amenity, provided by the extent and variety of natural features and landscapes.	Maximum demand on the number of cultural heritage item (n/ha)	Local communities, family
Inspiration for culture	Landscape features or species with inspirational value to human arts, etc. The inspiration and motivation for traditional owner and other cultural and historical values provided by extent and variety of natural features and landscapes	Maximum demand on the number of elements, number of handycraft (n/ha)	Local and regional communities, local and international visitors, local and international tourist
Spiritual inspiration	Landscape features or species with spiritual and religious value. Sense of place, amenity provided by the extent and variety of natural features and landscapes.	Maximum demand on the number of item (n/ha), number of elements, number of spiritual item (n/ha)	Local communities
Educational and scientific interest	Features with special educational and scientific value/ interest. The value of nature and species themselves, beyond economic or human benefits. The motivation for scientific and educational opportunity, provided by the extent and variety of natural features and landscapes.	Maximum demand on the knowledge/education facility, knowledge type	Local communities, local and international researcher

3.2 Mapping the local people's demand and preferences for ES

As illustrated by Table 6, a relatively high demand for ES has been documented in natural land-cover types, primarily in peat swamp forests, forest land, mangroves, and water bodies. The highest dominant value was observed mostly in regulating services. The category of regulating services entails climate regulation, nutrient regulation, flood protection, and air-quality regulation, all of which represent a high demand between 4 and 5 for the aforementioned subservices. Shrubland and rubber plantations both exhibit a high demand for climate regulation and air-quality regulation, indicating a value of 4 and 5, respectively. The peat swamp forest is clearly important for climate stabilization. According to Too et al. [96], a peat that is 10 metres deep is capable of storing 5800 tonnes of carbon/ha, compared to forest land, which can only store a maximum of 500 tonnes of carbon/ha. In Southeast Asia, peatlands store 42,000 million metric tonnes of soil carbon, and the drainage contributes to 1.3%–3.1% of current global emission (Hooijer et al., 2010). As reported by Kamlun et al. (2016), part of the forest in Klias Peninsula was damaged by the 1998 fires, which were connected to El Niño. The total carbon emissions released from the 1997–1998 fires are estimated to be between 0.8 and 2.6 Pg.C and affected the regional air quality (Van Der Werf et al., 2008). This is further demonstrated in Figure 3 (b), which, with a demand map, shows how climate regulation has decreased tremendously over the past 28 years. The map indicates that the land cover's capacity to regulate the climate on the Klias Peninsula has significantly decreased. Most of the in-demand land-cover types classified as 'climate regulation' are located in forests (peat swamp forest, mangrove, and forestland), shrubland, and rubber plantations. Moreover, water bodies were identified as regulating flood protection and are in high demand in the local community. As described by the interviewees, expanding the river will help regulate the water content and reduce flood rates, which have been alarmingly high in Klias Peninsula.

Table 6. Assessment matrix for the local people's demand for ES in Klias Peninsula

Land Cover Type	Σ Provisioning services	Crops	Livestock	Fodder	Capture fisheries	Aquaculture products	Wild foods	Timber	Fuel Wood	Energy Resources	Medicinal resources	Genetic resources	Fresh Water Resources	Σ Regulating services	Climate regulation	Nutrient regulation	Flood protection	Air quality regulation	Erosion regulation	Σ Cultural services	Recreation and ecotourism	Cultural heritage	Inspiration for culture	Spiritual inspiration	Educational and scientific interest
Peat Swamp Forest		0	0	0	3	0	4	4	4	0	2	0	0		5	5	5	4	0		4	4	3	4	4
Mangrove		0	0	0	3	0	4	3	3	0	2	0	0		5	0	5	4	0		4	4	3	4	4
Forest Land		0	0	0	0	0	4	3	3	0	2	0	5		5	5	5	4	0		4	4	3	4	4
Shrubland		0	0	0	0	0	4	3	4	0	2	0	0		5	0	0	4	0		3	0	0	4	4
Grassland		0	3	0	0	0	3	0	0	0	0	0	0		0	0	0	0	0		3	0	0	2	0
Oil Palm Plantation		5	4	2	0	0	4	0	0	0	0	0	0		2	0	0	3	0		2	0	0	2	4
Rubber Plantation		5	4	0	0	0	4	3	4	0	0	0	0		4	0	0	4	0		0	4	0	4	4
Barren Land		0	4	0	0	3	0	0	0	5	0	0	0		0	0	0	0	0		2	4	0	3	4
Water Bodies		0	3	0	4	4	0	0	0	0	2	0	5		0	0	5	0	0		4	4	0	4	4

Concerning the demand for cultural services, all five subservices (recreation and ecotourism, cultural heritage, inspiration for culture, spiritual inspiration, and educational and scientific interest) were assigned a value between 3 (medium relevant demand) and 4 (high relevant demand). It was also demonstrated that the demand for cultural services is concentrated in all forest land-cover types, water bodies, plantations, and barren land. Malaysia's beaches and attractive natural scenery are huge sources of tourism (Foo, 2016; Rahman et al., 2021). According to Sha et al. (2008) and Bernard et al. (2011), a large number of endemic and wildlife populations are located along the riverbanks and mangroves in Klias Peninsula. This provides a unique opportunity for ecotourism and scientific possibilities. The map presented in Figure 3 (c) shows a negative change in high relevant demand for recreation and ecotourism subservices. This demonstrates that the land-cover types that represent the demand for recreation and ecotourism are decreasing. According to Kamlun and Burger Arndt (2019), three of the five subservices of cultural services (recreation and ecotourism, cultural heritage, and educational and scientific interests) experienced a decline in their supply of ecosystem services from 137,562 hectares in 1985 to 91,849 hectares in

2013. Furthermore, Colding and Folke (2001) emphasised that most cultures in both west and east Malaysia believed in social taboos. In many traditional societies, taboos frequently guide human behaviour towards the natural environment. This social norm was also observed in Klias Peninsula, where the local people believe in conducting certain rituals before entering the forest. The local community also believes that there are other spirits protecting the pristine forest and preventing people from obliterating the area. The local population additionally expressed a high demand for rubber plantations in the context of cultural heritage, spiritual inspiration, and educational and scientific interest. The local people of Klias Peninsula claim that the rubber plantations are the cultural remains of their ancestors and are particularly essential to the population's livelihood.

As for provisioning services, human-occupied land-cover types, such as palm oil plantations, rubber plantations, and barren land, show a very high relevant demand for crops and energy resources. In Malaysia, oil palm plantations are a major contributor to the national economy. In 2012, a reported 4 million hectares of oil palm plantations (12% of the nation's land area) were planted in Malaysia (Sayer et al., 2012). Further elaborate that, in less than 100 years, palm oil has become a major subsistence crop commodity for the local people. Similarly, wild foods, timber, and wood used for fuel are also in high demand, predominantly those found in the peat swamp forest area. The demand for this type of subservice was also observed in mangrove, shrubland, and forest land, indicating a demand value between 3 and 4. In 1970, extremely abundant natural resources were discovered in Malaysia. Malaysia's capacity to provide these resources grew rapidly within 20 years (Sachs & Warner, 2001). Furthermore, Malaysia hosts the richest biodiversity in the world. The country's biodiversity contributes to environmental stability, food security, education, and the extensive number of natural resources that support human well-being. The demand for energy resources displays a high value of 5, specifically for barren land areas. Research has shown that Malaysia's energy supply is concentrated in urbanised areas. In the context of this paper, energy resources are derived from oil and gas, which are located outside of the local scale assessment. Burkhard et al. (2014) explained that these were integrated into their conceptual framework regarding the additional input of mapping ES. In order to meet the increased demand, the services must be imported from a location outside of the assessment area. Additionally, water bodies and forest land received very high relevant demand (5) due to their fresh water supplies. Malaysia has high rainfall, high humidity, high temperatures, and abundant forest cover that all contribute to the supply of freshwater resources. Sabah has 37 rivers, which provide 97% of the country's total water demands, with the remaining 3% coming from groundwater (Ho, 1996). The rivers' potential to both capture fisheries and aquaculture products in Klias Peninsula provides important food sources for the population (Hashim & Ismail, 2015), which is why the demand for rivers is classified as high relevant demand.

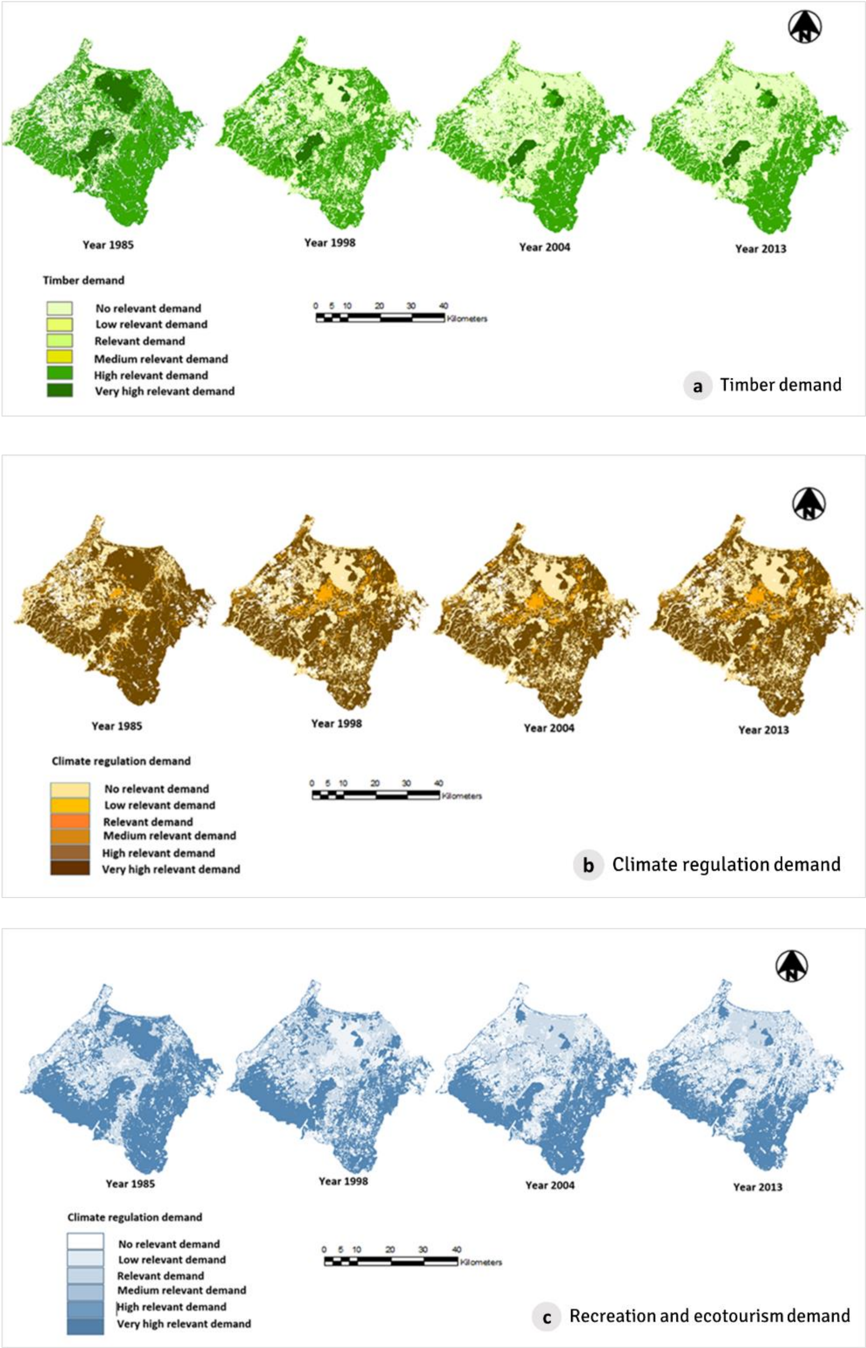

Figure 3. Maps of the local people's demand preferences for selected ecosystem services and the historical changes (1985-2013) in (a) timber, (b) global climate regulation, and (c) recreation, and ecotourism in the Klias Peninsula.

However, the demand maps for timber shown in Figure 3 (a) convey a severe fluctuation in all the forest land-cover types within 28 years of assessment. Prior to 1985, when the protected area was gazetted, the peat swamp forest was open for logging concessions (Phillips, 1998). The logging activities resulted in a further drainage system to benefit logging transportation. This drainage system facilitated excessive drainage from the peat swamp forest, causing the peat to dry and making it susceptible to fires (Kamlun et al., 2016). It was further reported by the authors that more than half of the forest area in Klias Peninsula disappeared from 142,713 hectares to 73,403 hectares between 1985 and 2013. This supports the information presented in Figure 3, which suggests that most of the ES land-cover types demanded by local people are located in forest areas, where the majority of the ecosystem's supplies are located. Thus, an unintentional magnitude of human demand for solitary ES has an undesirable impact on both the quality and availability of other ES. Globally, this trend has led to an increase in several services, such as provisioning services, but others, particularly regulating services, have experienced a decline (UNEP-WCMC, 2010).

In tropical forests, a wide range of ES can be discovered, and their continuous supply depends on efficient and effective management against deforestation and forest degradation. Emphasizing land cover history in tropical forest ecosystem research and policy promotes advantages in biodiversity conservation and contributes to safeguarding ecosystem functions and services in the tropical landscape (Martin et al., 2020). The mapping of land cover changes has been used to assess spatial correlations with geographical parameters to further guide decision-makers in the rational utilisation of ES in tropical forests (Li et al., 2022). A proper combination of remote sensing approaches helps to provide spatially explicit and historical long-term data to sustainably manage the tropical ecosystem. However, maps that relate successive multi-temporal land cover changes typically do not provide insights on the underlying transformations in the nature of the present, particularly the rate of change (David et al., 2022). Despite a lot of expert-based information on ES in tropical ecosystems, there is a lack of knowledge of the spatial distribution of ES from the perspective of local communities (Delgado-Aguilar et al., 2017). Spatially explicit data on ES helps to outline the distribution of ES and identify crucial areas as well as important information that can be used as a basis for local authorities.

3.3 Impacts of socio-demographic factors on ecosystem service demand in the protected area

Table 7 indicates the different sets of independent variables that were classified as the most important factors influencing the demand for provisioning, regulating, and cultural services in forests (peat swamp forest, mangrove, and forest land). The various ES appeared to measure different aspects of the respondents' perspectives on different forest types. Overall, ethnicity, source(s) of income, the village's distance from the protected area, period of residence, and education level were consistently important in shaping the population's perception of the demand for ES, although other factors also played significant roles.

The regression analysis of the relationship between socio-demographic characteristics and the demand for ES generates an interesting result. There are significant relationships between the preferences for land cover in tropical forests and the main drivers of demand for each service in Klias Peninsula, as shown in Table 6. The analysis conducted on provisioning, regulating, and cultural services for tropical forests integrates the following factors as independent variables to achieve the best result: village distances from the boundaries of the protected areas; gender; age; ethnicity; religion, which was categorised as either Muslim (the main religion in Malaysia) or non-

Muslim; source of income for farmers and non-farmers; total household members; education level; residential status; and period of residence. With other variables held constant, the source of income of farmers and non-farmers yielded a negative impact for all land-cover types in the categories of provisioning services and cultural services, with the exception of regulating services provided by the peat swamp forest. The estimated coefficients for sources of income show that non-farmers had a greater influence on the demand for provisioning services compared to farmers. The estimated coefficients for the farming status in the context of provisioning services offered by the peat swamp forest, mangrove, and forest land are statistically significant at 1%, 10%, and 5% levels, respectively. The estimated coefficients representing the demands of non-farmers for the peat swamp forest, mangrove forest, and forest are -0.113, -0.045, and -0.067. These coefficients demonstrate that an additional non-farmer would decrease the demand for provisioning services by 11%, 4.5%, and 6.7% less than farmers. Hence, non-farmers have less preference for forests than farmers. Environmental concerns associated with agriculture are mainly related to sustainable resources based on dependency on agricultural production. In contrast to non-farmers, farmers were more reliant on agricultural produce and forestry as subsistence security, resulting in an acceleration of consumption of natural forest products (Scherr & McNeely, 2008). The model introduced by Scherr indicates that as a result of population growth, limited access to land, or access to only poor and fragile land, poor people living in rural areas place increasing pressure on natural resources. The unrelenting pressure will, therefore, increase environmental degradation, which jeopardises food security and encourages land-conversion activities (Vlek, et al., 2017). In our study, all five regression models (source of income) indicate that farmers have a higher degree of demand for services offered in all forest area types, including provisioning, regulating, and cultural services. The regulating services found in the peat swamp forest area are excluded from this statement. These estimated coefficients are statistically significant at the 1% level for all models of regulating and cultural services, except for the cultural services demand for the peat swamp forest, which is significant at the 5% level.

Table 7. Multiple regressions of socio-demographic characteristics that influence the ES demand for tropical forests on the Klias Peninsula.

Predictor	Provisioning Services			Regulating Services			Cultural Services		
	Peat swamp forest	Mangrove	Forest land	Peat swamp forest	Mangrove	Forest land	Peat swamp forest	Mangrove	Forest land
Constant	0.219	-0.122	0.394	2.364	1.586	2.281	-0.383	-0.318	-0.102
Village distance (0= < 1000m from PA, 1= > 1000m from PA)		**0.093**			**0.219**		**0.260**	**0.156**	**0.143**
		(0.028)***			(0.109)**		(0.102)***	(0.087)*	(0.069)**
Gender (0=Male, 1=Female)			**0.075**						
			(0.028)***						
Ethnicity	**0.042**	**0.032**	**0.032**				**0.105**	**0.103**	**0.041**
	(0.010)***	(0.008)***	(0.008)***				(0.028)***	(0.024)***	(0.019)**
Religion (0=Muslim,					**0.459**	**0.487**			**0.267**
1=Non-Muslim)					(0.199)**	(0.254)*			(0.126)**
Source of income (0=Farmers, 1=Non-farmers)	**-0.113**	**-0.045**	**-0.067**		**-0.438**	**-0.593**	**-0.242**	**-0.252**	**-0.174**
	(0.034)***	(0.027)*	(0.029)**		(0.105)***	(0.135)***	(0.098)**	(0.084)***	(0.067)***
Education level							**0.059**		**0.045**
							(0.036)*		(0.024)*
Residential status (0=Resident, 1=Non-Resident)				**0.158**					
				(0.181)***					
Periof of residence (Years)				**0.131**	**0.099**	**0.147**			
				(0.049)***	(0.040)***	(0.051)***			
r^2	**0.140**	**0.135**	**0.117**	**0.113**	**0.126**	**0.146**	**0.112**	**0.143**	**0.080**

Note: ***Significant at the 1% level, **Significant at the 5% level, *Significant at the 10% level; standard error is pre-sented in parenthesis; unstandardized coefficients are displayed outside the parenthesis. The regression outputs above only show statistically significant results.

Our results also reveal that ethnicity is a positive determinant of demand for all forest types regarding both provisioning and cultural services, which have been ranked at the 1% level (significant). However, this assertion does not include cultural services found on forest land, which exhibit a 5% significance level for the ethnicity variable. These findings show that different races have similar needs for ecological services. Additionally, gender (1% significant level) scores were positively related to the demand for provisioning services found in forest land ecosystems. Women tended to have higher scores than men, by 0.075 units. As stated by the IPCC (2022), the value assigned to people by the assessment determines their access to the corresponding resource. Essentially, the values reveal the social demographic structures, such as class, gender, and ethnicity, that determine an individual's ability to benefit from ecosystem services. This finding corroborates the global and regional study conducted by Sunderland et al. (2014) and Mwangi et al. (2011). The results of this study, a multivariate analysis, determined that women are significant contributors to their household income, which is widely determined by their access to forest-sourced products. Sunderland et al. (2014) also reported that, in Asia, the majority of unprocessed forest products and wild plant food are collected by women. The fact that women in female-headed households contribute more to their family's income based on access to forest products than women in male-headed households is unsurprising since female-headed households tend to have one less active male to collect products. As in the case of the Klias Peninsula, women depend more on forest produce than men.

A village's distance from an area offering ES additionally increases demand for cultural services, specifically at the 1% level for peat swamp forest, at the 10% level for mangrove, and at the 5% level for forest land. The results further demonstrate that the distance influences the demand for both provisioning and regulating services in mangroves; this is represented by the significance values of 1% and 5%. The estimated coefficient suggests that as the distance between the village and the protected area increases by more than 1000 m, the demand for regulating services in the peat swamp forest and forest land will increase by 9.3% and 21.9%, respectively. According to Meijaard (2013), deforestation can lead to temperature increases due to a loss in the canopy's ability to reflect and absorb solar radiation; changes in evaporative cooling additionally exaggerate this phenomenon. According to the authors of this text, 33% of the respondents acknowledged that one environmental benefit of forests is that they reduce temperatures. The estimated coefficient of education level for peat swamp forest (0.059) and forest land (0.045) indicates that with every additional year of education an individual has received, the demand for cultural services in both peat swamp forest and forest land goes up by 5.9% and 4.5%, respectively, in and around the area. This reveals that in Klias Peninsula, as the level of the local population's education increases, the demand for cultural services intensifies.

The religion variables for cultural services were found to have positive effects on the demand for forest land (5% level of significance), as well as for the regulating services in peat swamp forests and mangroves, which are significant at the 5% and 10% levels, respectively. The estimated coefficients for religion indicate that the demand for cultural and regulating services increases by more than 45%. This indicates that the religious composition of the village area is the dominant variable for cultural services, which in this case is represented by the religion of Islam (Meijaard et al., 2013).

The exploitation of natural resources is a key factor in the maintenance of human well-being. However, the pursuit of sustaining livelihoods can fuel negative environmental and socio-economic outcomes. This statement is corroborated by the floods and fires that occur annually in Klias Peninsula as a result of overexploitation of the peat swamp forest (Kamlun et al., 2016; UNDP/GEF, 2006). As reiterated by Table 5, the most in-demand sub-services are regulating services for all forest types. Furthermore, the estimated coefficient for residential status in relation to demand for regulating services is statistically significant at the 1% level (refer to Table 7). The estimated coefficient representing the demand expressed by the community indigenous to Klias Peninsula for peat swamp forest is a beta unstandardized coefficient of 0.158. The result further highlights that the period of residence for people living in Klias Peninsula is determined by regulating services in peat swamp forests, mangroves, and forest land. When the individual's access to regulating services provided by the aforementioned areas increases, so does the period of their residence in the area, represented by significance values of 13.1%, 9.9%, and 14.7%. This result is supported by Kardooni et al. (2014), who suggest that residential status and property ownership influence how individuals engage with forest resources. This involves the individual's traditional knowledge with reference to the environment. However, our findings reveal remarkably dissimilar responses to those presented by Schoneveld et al. (2019). The team reported that the demands expressed by non-indigenous migrants have become highly significant for forest areas. Environmentally conscious migrants tend to pursue and use forest resources more effectively. Compared to newer residents, people who have lived longer on the Klias Peninsula express a higher demand for regulating services from all forest types. This indicates that regulating services is determined by older populations, who are more likely to explore the forest for subsistence opportunities. More than 1.6 billion people worldwide depend on forests to sustain their livelihood. At least 350 million people live inside or close to forest areas and depend largely on these forests for subsistence and income. Of the 350 million people, approximately 60 million indigenous individuals are almost entirely dependent on the forests (Husain et al., 2018).

To interrelate the matrix model findings with the regression statistical model, the results show that of all the models presented in Table 5, the squared correlation coefficient (r^2) indicates that the degree of association between independent variables and dependent variables is low. The lower r^2 is due to some unexplained variations in the dependent variables that are not fully captured among the independent variables. Some of these important variables are omitted from the regression estimation. Therefore, to further improve the model, we suggest including variables that are important for socio-demographic factors because they may have a profound influence on the demand for ES at a local scale.

4. CONCLUSIONS

After completing an analysis of changes in land cover and respective ES indicators sourced from a protected peat swamp forest and the surrounding area in Klias Peninsula, Sabah, Malaysia, the authors concluded that the peat swamp forest is an important ES provider. We found that there is accessibility to a range of ES that connects the indicators. A large number of indicators representing the demand for ES from the perspective of the local community have been produced. These indicators can also be used for a comprehensive assessment and mapping of ES, particularly when working in tropical forest regions. The findings of the study also clearly suggest that local residents prefer regulating services to provisioning and cultural services. However, most of the ES demand is found in forest land-cover types and water bodies land-cover types, as the results indicate. We were able to establish the demand patterns demonstrated by local communities and socio-demographic factors using multiple regression models. A range of ES that measured different aspects of respondents' perspectives on different forest types revealed that ethnicity, sources of income, the village's distance from the protected area, length of residence, and education level were consistently influential in shaping the population's demand for ecosystem services in Klias Peninsula, although other factors also played significant roles. Subsequently, the demand analysis undertaken on provisioning, regulatory, and cultural services for tropical forests predominantly accounted for the village's distance from the protected area's limits. In particular, our study illustrates the benefits of employing an intuitively straightforward suite of ES applications. In terms of policy implications, such information about the visual spatial distribution of the demanded ES is important for managers in land-use planning to highlight the hotspot areas that can be used to zone a particular area for further conservation purposes. Such baseline data can help decision-makers plan the preservation of a complex ecosystem while maintaining the social welfare of the community that lives adjacent to the protected area.

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