Expert-Based Approach on Mapping Ecosystem Services Potential Supply Incircling a Protected Areas by Integrating Matrix Model Assessment

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Abstract. The concept of ecosystem services was introduced into global policy to consolidate both conservation and development to interconnect the discourse between biodiversity and sustainable development for the benefit of human well-being; this encourages conservation and land use planners to achieve both ecological and social goals. Mapping the potential supply of ecosystem services is necessary for continuous monitoring of such services to ensure the sustainable management of natural resources to support decision-making. Therefore, this study presents a multifaceted methodological framework for mapping ecosystem services potential supply surrounding a protected area. We integrate a non-monetary ‘Matrix Model’ assessment with an expert-driven approach to assess the potential supply from a holistic perspective. Experts and stakeholders dealt with Likert scales to weigh multiple land cover supply of ecosystem services. Our study shows that using an integrated approach to map ecosystem services not only minimizes uncertainties but is also important for the evaluation of ecosystem services. The integration process can also be an interactive approach between scientists and stakeholders to improve mutual understanding regarding resource management. The selected services and land cover data can be an effective medium to visually exhibit forest function and the services of a protected area; these can work as scheming tools that can contribute to an effective policy measurement for the sustainable conservation of protected areas.

1. Introduction

Mapping the ecosystem and their services is essential in development planning and decision processes for the benefit of society. Aspirations of ecosystem services mapping are to allow the value of nature visible by developing indicators and converted it into visual data system [1]. As been emerged numerously, ecosystem services are the benefit which people derive from nature [2,3]. The ecosystem services concept of holistic research approach was made by Millenium Ecosystem Assessment (MA), to bring forward policy tool to achieve sustainable use of natural resources [2,4]. The institutional perspectives are to integrate insights of long-term human impact on the use of ecosystem services based on the existing management policies. However, MA did not deliver a complete operational method to execute the full concept to assist policy makers and researchers with sufficient tools [5,6].

The dispute of standardized approaches to quantify ecosystem services has become a crucial issue for many scientists and decision makers [7-10]. As a result, variation range of reports with widely differing aims, makes it difficult for policy makers to use the credibility of the assessment results [4].
In order to translate the ecosystem services concept in landscape planning, integrated and easily applicable assessment are essential for that purpose [8,11]. Recognizing this urgency, a new ‘Matrix Model’ approach was introduced [12,8,13,14]. It consists of a holistic appraisal of assessment that integrate quantitative data and expert judgements to access landscapes’ capacities in delivering ecosystem services. It has been used widely and successfully in developing countries [15,16,17]. Yet, there are still untested in most of the region in the world [18,19]. As far as the literature exhibit, Malaysia by far has been lacking to acknowledge the ecosystem services assessment as well as monitoring the status of ecosystem service potential supply. Therefore, the study focuses on extending a more transparent analysis of the ‘Matrix Model Assessment’ to assess the ecosystem services potential supply in different type of landscape surrounding a protected area.

2. Materials and Methods

2.1. Study Area

This study was conducted in the District of Beaufort in Southwestern part of Sabah in East Malaysia (Figure 1) where an extensive wetland area is located. This wetland lowland plain is often referred to as Klias Peninsula. Beaufort occupy approximately 466,804 ha of land. This area receives high annual rainfall between 2,500 - 3,000 mm. The remaining area of Klias Peninsula forms the greater wetlands and constitutes the ‘buffer zone’ to the ‘core’. It is facing the South China Sea on the west and surrounded between Kimanis Bay to the North and Brunei Bay to the south, covering both Beaufort and Kuala Penyu Districts administration boundaries. The area is mostly being gazetted as a forest reserves (red boundaries indicated as forest reserves in figure 1). Some are gazetted as a fully protected (Class 1) peat swamp forest located between the 115˚.45’ - 115˚.72’N and 5˚.42’ - 5˚.15’E.

Figure 1. Location of Klias Peninsula, Sabah, Malaysia.

2.2. Historical Land Use and Land Cover Data Preparation

The first step in assessing the potential supply of ecosystem services is to generate land cover/land use map of the study area. In the case of Klias Peninsula, we obtained time series satellite images from the United States Geological Survey (USGS) EarthExplorer (see http://earthexplorer.usgs.gov/, Path/Row: 118/56) that was freely available. The earliest satellite image was from the Landsat Multispectral Scanner (MSS), taken on June 29, 1985. The Landsat 5 Thematic Mapper (TM) imagery data was obtained on November 24, 1998 and June 17, 2004 and Landsat 8 OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor) was taken on April 23, 2013.
Supervised classification using the maximum likelihood classification rule was applied to create the land cover change map of the study area. According to Hong et al. (1998), the maximum likelihood rule takes the most variables into account in classification scheme and thus the most accurate classification system. The supervised classification approach also generates statistics (i.e. mean, variance/covariance) from training samples to generate the thematic map. Each pixel was then clustered into the class to which it most likely belongs. Nine classes of the land cover classification were used and defined as: (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 limitation of using the medium resolution Landsat images is that, when defining the “barren land” class it includes all the combination of exposed soil, non-vegetative and built-up areas which have similar spectral values. This condition made it impossible to distinguish the differences between the classes for the classification processes. Finally, accuracy assessment was performed using reference data that were collected by stratified random sampling within strata. The overall accuracy obtained for the Klias Peninsula were more than 88% (±4% margin of error). The result was presented in Kamlun et al. [20].

2.3. “Matrix Model” approach on valuation of ecosystem services

In the ecosystem services aspects, the process to evaluate the services values comprises of three major components which include selecting the key ecosystem services, quantifying the underlying physical parameters, and valuing ecosystem services [21]. The key ecosystem services serve as the ecosystem functions which is locally available and at some point cannot be traded with other region. According to Costanza et al. [7], the ecosystem functions subsist variously to the habitat, biological or system properties of ecosystems. The second component consists of physical parameters using spatially explicit process models [21]. An interesting point was introduced by Müller and Burkhard [22], which shows that ecological indicators can be used as a communication tools to facilitate a simplification of a high complex human-environmental systems. The sets of indicators are a component or a measurement of environment conditions that aggregate the information to a certain thematic field. The third component is to convert the physical data into value either in monetary or in non-monetary value. Which in our case the interest would be the non-monetary value of using the ‘Matrix Model” approach introduced by Burkhard et al. [8,12,13,14].

The “Matrix Model” assessment of ecosystem services is the most practicable approach that can be used to present a more holistic overview of ecosystem services aspects. This can be applied in terms of policy, institutional and local participation in sustainable management. The basic idea of the assessment was to point out a strategic analysis to evaluate the ecosystem services in spatial manner. Prior to the commencing method, the process begins with utilizing any relevant land cover and GIS databases as the first approach. The second step was to initialize all selected and relevant services for their quantification of ecosystem services value. The third step was to link both land cover data and expert judgement using Likert-type scale from 0-5. The ecosystem services in the x-axis and land cover type in the y-axis [8,12].

2.4. Site-Based Expert Interview and Data Validation

To further assess the potential supply of ecosystem services in Klias Peninsula, we conducted semi-structured site-based expert interviews using snowball sampling method. This assessment was performed to validate and further evaluate the whole categories of sub-services potential supply in the area. There were 16 local experts selected based on their familiarity with the area and adequate background on ecological aspects in the study area [16]. Selected experts included ecologists, wildlife ecologists, hydrologists, protected area managers, nature conservationists, and foresters. The interviews were conducted individually to minimize any influence from other experts on the information provided. The next phase was to ask the experts opinion regarding the value of ecosystem services’ potential subservices supply. The experts were instructed to rank each subservice according to its relevance. Thirty-six sub-services were evaluated by using six-point Likert-type scale that were
scored as follows: “no relevant capacity’ (0), ‘low relevant capacity’ (1), ‘relevant capacity’ (2),
‘medium relevant capacity’ (3), ‘high relevant capacity’ (4), and ‘very high relevant capacity’ (5) [8].
The information from the matrix table was then converted to polygon attribute in GIS using the code
field as common identifier field in the land cover classification map [8].

3. Results and Discussions

3.1. Quantification of Ecosystem Services Potential Supply Value

Based on the presented result, relatively high potential capacities of ecosystem services supply
provided by the forests area (peat swamp forest, mangrove and forest land). The highest value is
shown mostly in ecological integrity from the value of 3 to 5, followed by regulating services where it
shows that peat swamp forest provides a very high potential supply capacity for global climate
regulation, nutrient regulation, flood protection and water regulation. It also shows that educational
and scientific interest was given a high value of 5 in the peat swamp area. The provisioning services
indicated that the highest potential supply of services is mostly located in forest land, particularly for
the following services; timber, fuel wood, genetic resources, and provision of shade and shelter.
Parallel with the result presented in table 2. the support of ecological integrity shows a high value for
all forest types between 3 and 5. Grounded by the information provided by the World development
Indicator, Malaysia has only 0.2% of world’s land area. However, the diversity of flora and fauna
species makes it one of the richest countries in the world in term of biodiversity per unit area. Further
proclaimed that Malaysia is one of the 12 mega-diversity countries in the world [23]. The rich
naturalness and biodiversity in this area contributes to the environmental stability, food security,
education and extensive amount of natural resources for the support of human well-being.

In other perspectives of human dominated land cover types, it appears that oil palm plantation,
rubber plantation, and barren land shows a low value of potential supply services and the support of
ecological integrity. It was validated by both literatures based expert data extraction and site-based
experts. The values between 3 and 0 were allocated to this land cover types. This phenomenon was
explained by Nijkamp et al. [24], who stated that immense amount of human activities contributes to
the loss of biodiversity at the same time threaten the ecosystem stability to provide human with its
goods and services. However, a high value of 4 was presented in ecological integrity for oil palm and
rubber plantation in metabolic efficiency and storage capacity (SOM). Based on the finding presented
by Khasanah et al. [25], soil carbon stock in oil palm plantation is relatively close to the measurement
in the forest area. It was also concluded that there is no net effect for the response of soil carbon in oil
palm plantation compared to forest land cover type [25]. It was also shown in table 2. that a high value
ranges from 3 and 5 in crops and livestock, can potentially supplied by the plantation area. In Malaysia
it was reported that an integrating farming system was established. Farmers are introduced with
planting oil palm and rubber plantation and integrate it with animal production. It has resulted a
successful integration for a high yield production for sheep and cattle in the plantation area [26,27].

In addition to this, the land cover type of water bodies is able to potentially provide the highest
capacity of capture fisheries, aquaculture product, fresh water supply (for provision services) and
educational and scientific interest (for cultural services). Similar to mangrove forest type where both
land cover type contains aquatic based environment where both contains water molecules. It also
shows a highest value in SOM in the support of ecological integrity where both gave the value of 5
and 4, respectively. Rivers in Malaysia are commonly reported to provide useful used for
transportation, irrigation, recreation and even provide protein in fish industries [28]. It is further
reported by Sha et al. [29], relatively high biodiversity and wildlife population are located along the
river banks and the mangrove of Klias Peninsula. This in return penetrated a high opportunity for
scientific and recreation possibility. In cultural services, again forests were given highest value
between 3 and 5 for all 6 subservices of; recreation and ecotourism, cultural heritage, inspiration for
culture, spiritual inspiration, and educational and scientific interest. Contrast to human modified
landscape where it shows that plantation area and most barren land was given a very low value for
cultural services apart from educational and scientific interest. It further reported by Foo [30], that a
scenic beauty of forest is highly preferred due to the natural landscape and physical features of complexity. Furthermore, the high biodiversity in the forest provide high potential for any educational and scientific purposes.

Table. 2. Ecosystem services assessment matrix illustrating the capacities of different land cover type to support ecological integrity and to potentially supply ecosystem services in the Klias Peninsula area.

| Land Cover Type       | Metabolic efficiency | Energy capture (radiation) | Reduction of nutrient loss | Storage capacity (SOM) | Abiotic heterogeneity | Biotic waterflows | Regeneration | Local climate regulation | Global climate regulation | Water purification | Flood protection | Pollution | Recreation and ecotourism | Cultural services | Educational and scientific interest |
|-----------------------|----------------------|-----------------------------|---------------------------|------------------------|----------------------|-------------------|--------------|--------------------------|------------------------|----------------|----------------|---------|---------------------------------|------------------|-----------------------------------|
| Peat swamp forest     | 1                    | 3                           | 0                         | 1                      | 2                    | 1                 | 2            | 3                        | 2                      | 3              | 2              | 2      | 1                              | 1                | 1                                 |
| Mangrove              | 2                    | 2                           | 1                         | 1                      | 2                    | 2                 | 1            | 1                        | 2                      | 2              | 2              | 1      | 2                              | 2                | 2                                 |
| Forest land           | 3                    | 3                           | 3                         | 3                      | 3                    | 3                 | 3            | 3                        | 3                      | 3              | 3              | 3      | 3                              | 3                | 3                                 |
| Shrubland             | 4                    | 4                           | 4                         | 4                      | 4                    | 4                 | 4            | 4                        | 4                      | 4              | 4              | 4      | 4                              | 4                | 4                                 |
| Grassland             | 5                    | 5                           | 5                         | 5                      | 5                    | 5                 | 5            | 5                        | 5                      | 5              | 5              | 5      | 5                              | 5                | 5                                 |
| Off-palm plantation   | 6                    | 6                           | 6                         | 6                      | 6                    | 6                 | 6            | 6                        | 6                      | 6              | 6              | 6      | 6                              | 6                | 6                                 |
| Rubber plantation     | 7                    | 7                           | 7                         | 7                      | 7                    | 7                 | 7            | 7                        | 7                      | 7              | 7              | 7      | 7                              | 7                | 7                                 |
| Barren land           | 8                    | 8                           | 8                         | 8                      | 8                    | 8                 | 8            | 8                        | 8                      | 8              | 8              | 8      | 8                              | 8                | 8                                 |
| Water bodies          | 9                    | 9                           | 9                         | 9                      | 9                    | 9                 | 9            | 9                        | 9                      | 9              | 9              | 9      | 9                              | 9                | 9                                 |

Note: The different colour of the following capacities explained as follows; 0/rosy for no relevant potential capacity, 1/grey green for low relevant potential capacity, 2/light green for relevant potential capacity, 3/yellow green represent medium relevant potential capacity, 4/blue green represent high relevant potential capacity, and 5/dark green are the very high (maximum) relevant potential capacity for each subservice.

3.2. Mapping of Ecosystem Services Potential Supply Change Trends
The result derived from table 2, are combined with the land cover classification map of different years to produce the support of ecological integrity map, provisioning services, regulating services and cultural services potential supply. Each service and the support of ecological integrity was illustrate using the following example; ecological integrity using metabolic efficiency, provisioning services using timber supply, regulating services using global climate regulation, and cultural services using recreation and ecotourism. The maps are presented in figure 2 and figure 3. The dark brown colour presents a high value of metabolic efficiency, whilst the light yellow presents a low value of metabolic efficiency in the study area. Parallel to the decrease of metabolic efficiency, the amount of energy that is necessary to maintain specific biomass in this area has fluctuated tremendously which is clearly shown in figure 2. (Yellowish and bright colours). In the context of ecological integrity, Müller and Burkhard [12] illustrate that the concept preserves against general disturbances of the self-organizing ecological systems. Any alterations of the ecological integrity will increase or decrease the supplies of ecosystem services.

Similar to timber supply, it is illustrated in figure 3 that there is a large amount of deterioration of provisioning services in this area particularly in the northern part of Klias Peninsula. The same pattern goes to global climate regulation. It is reported that Binsuluk Forest Reserve was partially destroyed because of fire during El-Nino in 1998 [20]. It occurred again in 2003 affecting the remnant patch to degrade and finally disappeared. This phenomenon is causing the fluctuation and worsening the function and potential supply of Klias Peninsula to provide services to the local community in terms of provisioning services. In figure 3 (a), it appears that the most prominent high potential capacity for provision services are wild foods, timber, fuelwood, energy resources, genetic resources freshwater resources, and provision of shade and shelter. However, in 1985 all these subservices showed to have more than 100,000 ha in 1985. Unfortunately, in 2013 it presents a fluctuation of almost 50% of the total area [20].

It is reported by Brander et al. [31], wetland represent the highest capacity and net value in provisioning services for fish, fuel woods and other materials in Southeast Asia. However, he further stated that land use pressure and population development are the main driver of change for this forest type causing the ecosystem services to tremendously fluctuate. This is the same issue that was face by
Klias Peninsula, where the increase of population in this area causing the pressure for the state lands to be converted to human settlements [32]. Numerous villages are located adjacent to the area of the protected forest reserved. An increase of population has caused the encroachment into the nearby protected forest boundaries. In relations to this, further implementation of the government on agricultural expansion policy in Klias Peninsula had led to the alienation of this state lands area. The periphery within the reserved forest was formerly extensive peatland; however, most of the surrounding areas were converted to agriculture plantations [33]. The soils of the peat swamp forest are naturally waterlogged, so the risk of catching fire should be avoidable [34]. However, the agricultural drainage canals system that was introduced into this area is hampering the capacity of the peat swamp forest to provide its important function. The excess drainage of freshwater from the peat forest may disturb the balance. In addition to that, the drainage of the peat soils is causing the the topsoil and vegetation to dry up quickly during the dry season, making it highly combustible. As a result, massive fires frequently took place in the forest reserve since 1997 up until 2010 [35]. Therefore, most of the services of ecosystem potential supplied has tremendously deteriorate affecting unfavourable outcome to the local people well-being in this area.

Figure 2: Maps of ecological integrity historical change (1985-2013) for metabolic efficiency in the Klias Peninsula area (Values of selected and detailed individual ecosystem function displayed in table 2).
Figure 3: Maps of ecosystem services supply historical change (1985-2013) for (a) timber, (b) global climate regulation, and (c) recreation and ecotourism in Klias Peninsula area (Values of selected and detailed individual ecosystem services supply displayed in table 2).
4. Conclusion
We initiate a more transparent analysis of holistic ecosystem services by interpolating thematic analysis and “Matrix Model” approach to map different potential supply using land cover classification images. We learn that the method pertained an innovative process to comprehensively map multiple ecosystem services at a local scale. Our study also shows how that by creating visualization on the changes of multiple ecosystem services potential supply can support land use planning. Particularly, in the case of southwestern, Sabah, Malaysia areas where land use conversion to cultivated area has impacts on the supply of other ecosystem services. At present, drastic degradation inside the protected area, in turn, generated tremendous demands by the adjacent local communities to convert the land to agricultural use, particularly palm oil plantations. However, this pressure will increase the environmental impacts on the remnant of the peat swamp forest area. At the same time, decreasing the functionality and services of the ecosystem in terms of regulating, provisioning and cultural aspects. With the ecosystem services approach we offer a constructive and illustrative approach that can be specified to inform the land use planning for future undertaken in policy making.

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5. References
[1] TEEB – The Economics of Ecosystems and Biodiversity 2013 Guidance Manual for TEEB Country Studies. Version 1.0. Available via: http://www.teebweb.org/resources/guidance-manual-for-teeb-country-studies/
[2] MA (Millennium Ecosystem Assessment) 2005 Ecosystems and Human Well-Being: Synthesis (Washington DC: Island Press).
[3] De Groot R S, Wilson M A and Boumans RMJ 2002 A typology for the classification, description and valuation of ecosystem functions, goods and services Ecological Economics 41(3) 393–408. http://doi:10.1016/S0921-8009(02)00089-7
[4] Seppelt R, Dormann CF, Eppink F V, Lautenbach S and Schmidt S 2011 A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead Journal of Applied Ecology 48(3) 630–636. http://doi:10.1111/j.1365-2664.2010.01952.x
[5] Armsworth P R, Chan K M A, Daily G C, Ehrlich PR, Kremen C, Ricketts T H and Sanjayan M A 2007 Ecosystem-Service Science and the Way Forward for Conservation Conservation Biology 21(6), 1383–1384. http://doi:10.1111/j.1523-1739.2007.00821.x
[6] Polasky S, Tallis H and Reyers B 2015 Setting the bar: Standards for ecosystem services. Proceedings of the National Academy of Sciences of the United States of America 112(24) 7356–61. http://doi.org/10.1073/pnas.1406490112
[7] Costanza R, Arge R, Groot R D, Farberk S, Grasso M, Hannon B, Sutton P 1997 The value of the world’s ecosystem services and natural capital Nature 387 253–260 http://doi.org/10.1038/387253a0
[8] Burkhard B, Kroll F, Nedkov S and Müller F 2012 Mapping ecosystem service supply, demand and budgets Ecological Indicators 21 17–29. http://doi.org/10.1016/j.ecolind.2011.06.019
[9] Petter M, Mooney S, Maynard S M, Davidson A, Cox M and Horosak I 2013 A Methodology to Map Ecosystem Functions to Support Ecosystem Ecology and Society 18(1) 31. http://doi.org/10.5751/ES-05260-180131
[10] Vorstius A C and Spray C J 2015 A comparison of ecosystem services mapping tools for their potential to support planning and decision-making on a local scale Ecosystem Services 15 75–83. http://doi:10.1016/j.ecoser.2015.07.007
[11] De Groot R S, Stuip M A M, Finlayson C M and Davidson N 2006 Valuing wetlands: guidance for valuing the benefits derived from wetland ecosystem services Ramsar Technical Report No. 3/CBD Technical Series No. 27. (Ramsar Convention Secretariat, Gland, Switzerland & Secretariat of the Convention on Biological Diversity, Montreal: Canada) ISBN 2-940073-31-7.

[12] Burkhard B, Kroll F and Müller F 2009 Landscapes’ Capacities to Provide Ecosystem Services – a Concept for Land-Cover Based Assessments Landscape Online 1–22. http://doi.org/10.3097/LO.200915

[13] Burkhard B, Kandziora M, Hou Y and Müller F 2014 Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification Landscape Online 31 1–32. http://doi.org/10.3097/LO.201434

[14] Burkhard B, Müller A, Müller F, Grescho V, Anh Q, Arida G, Bong S 2015 Land cover-based ecosystem service assessment of irrigated rice cropping systems in southeast Asia – An explorative study Ecosystem Services 14 76–87. http://doi.org/10.1016/j.ecoser.2015.05.005

[15] Kaiser G, Burkhard B, Römer H, Sangkaew S, Graterol R, Haitook T … Sakuna-Schwartz D 2013 Mapping tsunami impacts on land cover and related ecosystem service supply in Phang Nga, Thailand Natural Hazards and Earth System Sciences 13(12) 3095–3111. http://doi:10.5194/nhess-13-3095-2013

[16] Islam S Ahmed S and Burkhard B 2014 Landscape’s capacities to supply ecosystem services in Bangladesh: A mapping assessment for Lawachara National Park Ecosystem Services 12 128–135. http://doi.org/10.1016/j.ecoser.2014.11.015

[17] Paudyal K, Baral H, Burkhard B, Bhandari S P and Keenan RJ 2015 Participatory assessment and mapping of ecosystem services in a data-poor region: Case study of community-managed forests in central Nepal Ecosystem Services 3 81–92. http://doi.org/10.1016/j.ecoser.2015.01.007

[18] Naidoo R, Balmford A, Costanza R, Fisher B, Green R E , Lehner B, Ricketts T H 2008 Global mapping of ecosystem services and conservation priorities PNAS 105(28) 9495–9500. http://doi.org/10.1073/pnas.0707823105

[19] Nelson E, Mendoza G, Regetz J, Polasky S, Tallis H, Cameron D R and Shaw M R 2009 Modeling multiple ecosystem services , biodiversity conservation , commodity production , and tradeoffs at landscape scales Frontiers in Ecology and the Environment 7(1) 4–11. http://doi.org/10.1890/080023

[20] Kamlun K U, Bürger Arndt R and Phua M H 2016 Land Use Policy Monitoring deforestation in Malaysia between 1985 and 2013: Insight from South-Western Sabah and its protected peat swamp area Land Use Policy 57 418–430. http://doi.org/10.1016/j.landusepol.2016.06.011

[21] Grêt-regamey A and Kytzia S 2007 Integrating the valuation of ecosystem services into the Input – Output economics of an Alpine region Ecological Economics 3(4) 786-798 http://doi.org/10.1016/j.ecolecon.2007.02.026

[22] Müller F and Burkhard B 2012 The indicator side of ecosystem services Ecosystem Services 1(1) 26–30. http://doi.org/10.1016/j.ecoser.2012.06.001

[23] NRE - Ministry of Natural Resources and Environment 2006 Multilateral Environmental Agreements: Capacity Building and Implementation Project (MEA). Putrajaya, Malaysia. (ISBN 983-42860-1-5).

[24] Nijkamp P, Vindigni G and Nunes P A L D 2008 Economic valuation of biodiversity: A comparative study Ecological Economics 67 217-231 http://doi:10.1016/j.ecolecon.2008.03.003

[25] Khasanah N, Van Noordwijk M, Ningsih H and Rahayu S 2015 Carbon neutral? No change in mineral soil carbon stock under oil palm plantations derived from forest or non-forest in Indonesia Agriculture, Ecosystems & Environment 211 195–206. http://doi:10.1016/j.agee.2015.06.009
[26] Wahab H A 2001 Forages in Oil Palm and Rubber Plantations in Malaysia Proceeding of the 7th Meeting of the Regional Working Group on Grazing and Feed Resources 2001 Held from 2-7 July, 2001 in Manado, Indonesia. Available via: http://www.fao.org/ag/agp/agpc/doc/proceedings/manado/chap4.htm

[27] Abdullah F M, Azizan A R and Khusahry M Y 1997 Nutrient requirements and balancing diet for sheep under plantation crops Teknol. Ternakan. 12 51-59.

[28] Hashim R and Ismail N F 2015 Fish biomass in relation to water quality index as an indication of fisheries productivity of four selected fish species along the Galas River, Kelantan, Malaysia Procedia Environmental Sciences 30 38-43. http://doi:10.1016/j.proenv.2015.10.007

[29] Sha J C M, Bernard H and Nathan S 2008 Status and conservation of proboscis monkeys (Nasalis larvatus) in Sabah, East Malaysia Status and conservation of proboscis monkeys (Nasalis larvatus) Primate Conservation 23 107–120. http://doi.org/10.1896/052.023.0112

[30] Foo C H 2016 Linking forest naturalness and human wellbeing - A study on public’s experiential connection to remnant forests within a highly urbanized region in Malaysia Urban Forestry & Urban Greening 16 13–24. http://doi:10.1016/j.ufug.2016.01.005

[31] Brander L M, Wagendonk A J, Salman S H, Alistair M, Verburg P H, De Groot R S and Der Ploeg S V 2012 Ecosystem service values for mangroves in Southeast Asia: A meta-analysis and value transfer application Ecosystem Services 1(1) 62–69. http://doi.org/10.1016/j.ecoser.2012.06.003

[32] UNDP 2003 Multi-Disciplinary Assessment for Klias Forest Reserve, Klias Peninsula (Sabah). Kota Kinabalu

[33] Azmi R 2005 Klias Forest Reserve conservation plan: Beaufort District, Sabah. Kota Kinabalu. MAL/99/G31

[34] UNDP/GEF 2006 Peat Swamp Forests: Conservation and Sustainable. Malaysia. Hong S, Gillavry E and Raaphorst C 1998 Project Image Analysis: Holterberg area. E. Image Processing Laboratory (IPL), Geoinformatics, ITC Enschede, Netherlands

[35] Kamlun K U and Phua M H 2010 Assessing wetland vegetation fragmentation in Beaufort, Sabah using multitemporal satellite remote sensing, in: Proceedings of the Mrss 6th International Remote Sensing & GIS Conference and Exhibition 28 & 29 April 2010. Kuala Lumpur. Malaysia: Putra World Trade Centre