Development of landscape forest performance index to assess forest quality of managed forests

M Muhamad Afizzul1, Y Siti Yasmin1 and O Hamdan1
1 Geoinformation Programme, Forestry and Environment Division, Forest Research Institute Malaysia, 52109 Kepong, Selangor, Malaysia.

Email: afizzul@frim.gov.my

Abstract. Besides timber and economic benefits, forest ecosystems provide other ecosystem services related to biological diversity and environmental functions of forests. Assessing some of the ecosystem services, which can be an indicator of forest quality at a landscape level requires the use of geospatial technology to achieve it. The aim of this work is to develop a forest performance index at the landscape level for mangrove forests. Several ecosystem services were identified and selected as indicators. The target value was set for each indicator and calculated into percentage value, which indicates progression to the target value, combined from field and geospatial data. The forest performance index was then produced by combining all indicators to get an overall performance of one particular forest area with respect to the target. The index was developed and tested at one of the best managed mangrove forests in the world, which is Matang Mangrove Forest Reserve (MMFR) in Perak. Based on the index that has been developed, the forest quality of MMFR, which consists of 19 forest reserves, is classified as good forest with an overall score of 72 percent. Pulau Kecil and Telok Kertang forest reserves have shown a very good forest quality with an overall score over 80 percent. Other 17 forest reserves in MMFR shown good forest quality with a ranged index of 68.8 to 78.4 percent. This work can be a tool for assessing forest quality at landscape level for decision support in sustainable landscape management and can be applied on other regions.

1. Introduction

Forests play an important role in maintaining the environment as they provide ecosystem services to their surrounding and also to the world. Forests not only supports ecosystems and habitats, but they regulate water cycle, purifies the air, stabilize climate, support biodiversity and others. Healthy forest ecosystems provide a wide range of services that includes society’s basic needs, cultural or spiritual values and also economic processes. All these bring benefits either directly or indirectly to human society. Some of the services like timber, food, fuel and fiber provide by these forests can be quantified and valued in a monetary unit while others are hardly quantified and often considered in economic decisions.

Over the past decade, many studies related to valuing and monitoring services from the forests have been conducted in different regions [1-4]. The most common monitoring activities nowadays is the monitoring of forest extents due to deforestation and desertification, which caused by human activities and climate change, are one of the the major challenges to sustainable development [5-7]. With recent advances in geospatial technology, the use of this technology is becoming more prominent in recent years. Many studies have utilized remote sensing data to map and monitor forest extents in order to get an accurate estimation of the forest extents.
Remote sensing not only been used to monitor the forest extents, but also to quantity and monitor biophysical properties of the forests [8-11]. Above ground biomass were quantified by using radar images such as Radarsat, ALOS Palsar, Sentinel and others [12-14]. There are studies on estimating structural variables, such as stand density, basal area, volume and others using remote sensing data, have also been carried out. Most studies in recent years have used light detection and ranging (LiDAR) technology for better estimation of forest parameters [15-17]. However, studies on evaluating forest quality especially at a landscape level is still low in numbers despite there a numerous study on assessing and monitoring forest quality at site level have been made. Several studies have attempted to assess the forest’s quality by using geospatial technology [18-19].

One of the challenges in assessing the quality of the forests is there are no standard definition on the forest quality itself. Different persons or managers define it differently. None of past studies have used same indicator in assessing their quality of the forests. However, some of the studies have used several indicators such as basal area and volume as one of the criteria to assess their forests. This study has attempted to develop one index which comprises of several components and indicators to assess the quality of mangrove forests via the utilization of geospatial technology. This is to ensure the valuation of all mangrove forests in this country can be successfully done.

2. Methodology

2.1. Development of forest performance index

The development of forest performance index involved several steps. At the initial stage, forest performance index framework for assessing forest quality of mangrove forests was carefully developed. The framework consists of several components which are spatial, flora, fauna, carbon, soil and hydrology as shown in Figure 1. Each component consists at least one indicator that represents the quality of their respective component and each indicator has been given an equal weight. Spatial component has two indicators which is gazetted land and area contribution. Flora component also has two indicators which are basal area and volume. Other components such as fauna, carbon, soil and hydrology consist only one indicator.

![Figure 1. Forest performance index framework](image)

Another important consideration during developing the framework is the availability, validity and reliability of the data. Data collection and analysis were carried out after the forest performance index framework has been finalized. Multiple sources of data have been collected and analyzed in this study. The main source of data is mainly from field data collection. An ancillary data such as geospatial data...
and past research data have also been used to obtain minimum, mean/average/median, and maximum values. Some of raw data need to be converted and normalized for accurate comparison. Based on the values obtained, a target value was set for each indicator using proximity-to-target (PTT) approach [20]. The performance of each indicator will be based on its relative position to the target. The calculation of PTT value is shown in equation 1 below. High PTT value indicates good quality where that particular indicator is almost reaching the target. After PTT value of each indicator had been calculated, the FPI was calculated by aggregated all the indicator values. The FPI value would range from 0 which indicates lowest performance and 100 which indicates highest performance.

\[ PTT = \frac{[\text{Target} - \text{min}] - (\text{Target} - \text{raw data})}{\text{Target} - \text{min}} \times 100 \] (1)

2.2. Data processing and analysis

One test site has been selected to test the index and Matang Mangrove Forest Reserve (MMFR) was chosen for this purpose. Located at Taiping, Perak, Malaysia, MMFR is considered as one of the best managed mangrove forests in the world. MMFR consists of 19 forest reserves, as shown in Figure 2, with a total extent estimated at 40,043.03 ha in year 2016 [21]. Forestry Department of Perak State manages the MMFR with an operational from three (3) forest administrative ranges located at Kuala Sepetang, Kuala Trong and Sungai Kerang. All areas within MMFR were assigned to either one of the four management zones, which are protective forest, restrictive productive forest, productive forest and unproductive area. The structural and compositional variations within and between each zone in MMFR makes it an appropriate as a test site for the development of the index which later be applied to other sites.

![Figure 2. Location of 19 forest reserves under MMFR that were chosen as a test sites for the development of landscape forest performance index.](image)

To analyse forest performance index at landscape level, geospatial data were used as a main data to map and evaluate each of the forest reserve under MMFR. Geospatial data such as permanent forest reserves and compartments boundary, management zones and logging histories were acquired and
processed together with others data such as field inventory and satellite images to calculate the PTT of each indicator for each forest reserve. Most of the indicators used logging history data, forest reserves boundary and field inventory data to calculate the PTT. Landsat TM data was used to calculate yearly accretion and erosion for each forest reserve. Analysis of forest performance index was made at three levels, which are overall MMFR, administrative range and forest reserve levels.

3. Results and Discussion

Based on the forest performance index that has been developed, overall scoring for MMFR is 72 percent. Details on each indicator’s performance are shown in Figure 3. Gazetted land and important bird area have the maximum scoring of 100. This is because of these two indicators have achieved the target that has been set. There are no areas in MMFR been degezetted from forest reserve and all areas in MMFR still remains an important bird area sites for migration birds. Erosion and accretion is the top three scorings among all indicators with a score of 91.6. Slow rate of erosion happens in mangrove forests as compared to other land uses since one of the functions of mangroves is to prevent or slowing down the rate of erosion at the coastal area.

![Figure 3](image)

**Figure 3.** Overall scoring for MMFR based on forest performance index that has been developed.

At a forest administrative level, Kuala Sepetang range has the highest overall scoring with an overall score of 72.6, followed by Sungai Kerang and Kuala Trong with an overall score of 72 and 70.9 respectively. Details on each indicator’s performance for each range are shown in Figure 4. Three indicators have similar scores which are gazetted land, important bird area and water quality index. Water quality index has the same score for each administrative range because the sampling activities that have been conducted in MMFR is not very extensive and an overall water quality index is calculated for the whole MMFR and not at the administrative or forest reserve level. In term of erosion/accretion, Kuala Trong has the highest score with a score of 96.3 followed by Sungai Kerang and Kuala Sepetang with a score of 93.5 and 89 respectively. Despite being superior in term of erosion/accretion, Kuala Trong range has the lowest score among the other two ranges in term of carbon, basal area and volume with a scores of 42.2 and 46.3. This may cause by stand age across Kuala Trong range is lower than the other two ranges and also fewer protective zones been assigned in this range as compared to Kuala Sepetang and Sungai Kerang ranges.
Figure 4. Overall scoring at administrative level in MMFR based on forest performance index that has been developed.

At a forest reserve level, only two forest reserves achieved an overall score over 80. Those forest reserves are Jebong and Sungai Sepetang forest reserves under Kuala Sepetang forest range. Both forest reserves have scored 83.2 and 80.4. Pulau Kalumpang which aslo under Kuala Sepetang forest range is amongst the top three quality forest with an overall score of 78.4. Pulau Gula forest reserve has became the lowest forest quality with an overall score of 64. Sungai Temerlok, Pulau Trong Selatan and Sungai Limau forest reserves are the top three quality forest for Kuala Trong forest range. However, their overall scores are lower than the top three forest reserves under Kuala Sepetang forest range with an overall score of 72.4, 71.9 and 71.6 respectively. Sungai Tinggi forest reserve became the highest forest quality as compared to the other two forest reserves, which are Pulau Pasir Hitam and Sungai Nibong forest reserves, with an overall score of 72.5. In term of the performance of top three forest reserves between Sungai Trong and Sungai Kerang ranges, both show a comparable forest quality between those sites.

Ideally, a good quality forest is the natural forest. This means that the forests were keep as natural as possible by not allowing any silvicultural activities being carried out in these areas. Logically, natural forests would score higher than the other forests that includes several management zones especially productive zone where silvicultural activities can be done. One good example in this study is Pulau Kecil forest reserve under Kuala Sepetang forest range. Based on the index that has been developed in this study, the overall forest quality index is at the eight-place with an overall score of 68.8. Despite being superior in term of carbon, basal area and volume, which achieved a score of 100, the size of this forest reserve contributes to the decreasing of the overall score. This forest reserve only contributes to 0.1 percent of the total area of MMFR. Furthermore, the small extent of this forest reserve has also affected other indicator which is erosion/accretion.
There are some challenges in developing this index. One of major challenges is to select what indicator that must be included to produce one ultimate index. This is because of there are no standard definition of a good quality forests. It all depends on personal opinions. Most studied that have been carried out used different set of indicators to assess the quality of their forest. Furthermore, not all ecosystem services can be measured directly and calculated to monetary values which makes it more difficult to include as one of the indicators. Some of the ecosystem services that hardly be measured are climate regulation, disease and pest regulation, mental and physical health, esthetic values, spiritual and religious values and others. Other challenges in developing this index is assigning a weighted for each indicator. Each indicator has their own significance contributions to the surrounding environment and to the world.

Despite all the challenges faced in this study, one index specifically to assess forest quality of mangrove forests has successfully been developed. The use of geospatial data such as geographic information system (GIS) data and also remote sensing data in this study has demonstrated its usefulness in assessing forest quality at a landscape level, which makes comparison between forest reserves is possible. Several improvements can be done in order to improve the reliability of this index. This can be done by adding more indicators in this index and properly assigned each indicator with a right weight. Furthermore, improving the procedures on collecting and processing the raw data also can improved the accuracy of the index.

| Table 1. Overall scoring at forest reserve level in MMFR based on forest performance index that has been developed. |
|-----------------------------------------------|
| **Forest Reserve** | **Gazetted Land** | **Area Contribution** | **Basal Area & Volume** | **Important Bird Area** | **Water Quality Index** | **Erosion/Accretion** | **Carbon** | **Overall** |
|------------------|-----------------|----------------------|------------------------|------------------------|----------------------|--------------------|-----------|------------|
| KUALA SEPETANG  |                 |                      |                        |                        |                      |                    |           |            |
| Jebong           | 100             | 2.2                  | 53.9                   | 100                    | 68.3                 | 92.6               | 50.4      | 83.2       |
| Sungai Sepetang  | 100             | 2.1                  | 52.7                   | 100                    | 68.3                 | 91.0               | 47.3      | 80.4       |
| Pulau Kalampong  | 100             | 10.2                 | 66.8                   | 100                    | 68.3                 | 98.6               | 63.0      | 78.4       |
| Pulau Sangga Besar | 100          | 8.5                  | 38.0                   | 100                    | 68.3                 | 99.9               | 35.5      | 74.0       |
| Pulau Sangga Kecil | 100            | 2.9                  | 45.7                   | 100                    | 68.3                 | 96.9               | 43.0      | 73.4       |
| Cabai Malai      | 100             | 3.1                  | 44.3                   | 100                    | 68.3                 | 92.6               | 38.4      | 69.8       |
| Pulau Selinsing  | 100             | 7.3                  | 41.0                   | 100                    | 68.3                 | 95.1               | 37.6      | 69.6       |
| Pulau Kecil      | 100             | 0.1                  | 100                    | 100                    | 68.3                 | 99.5               | 100       | 68.8       |
| Telok Kertang    | 100             | 3.1                  | 74.7                   | 100                    | 68.3                 | 94.2               | 70.0      | 68.6       |
| Sungai Baharu    | 100             | 2.3                  | 52.5                   | 100                    | 68.3                 | 92.9               | 46.8      | 67.9       |
| Pulau Gula       | 100             | 3.1                  | 45.2                   | 100                    | 68.3                 | 87.9               | 42.4      | 64.0       |
| SUNGAI TRONG     |                 |                      |                        |                        |                      |                    |           |            |
| Sungai Temerlok  | 100             | 7.1                  | 44.7                   | 100                    | 68.3                 | 97.6               | 40.4      | 72.4       |
| Pulau Trong Selatan | 100          | 12.4                 | 27.8                   | 100                    | 68.3                 | 98.6               | 24.7      | 71.9       |
| Sungai Limau     | 100             | 7.4                  | 54.7                   | 100                    | 68.3                 | 96.9               | 49.8      | 71.6       |
| Pulau Trong Utara | 100            | 7.2                  | 50.2                   | 100                    | 68.3                 | 97.0               | 45.2      | 70.1       |
| Trong            | 100             | 1.8                  | 54.1                   | 100                    | 68.3                 | 91.2               | 50.9      | 68.2       |
| SUNGAI KERANG    |                 |                      |                        |                        |                      |                    |           |            |
| Sungai Tinggi    | 100             | 5.6                  | 53.1                   | 100                    | 68.3                 | 90.3               | 48.5      | 72.5       |
| Pulau Pasir Hitam | 100            | 11.7                 | 54.4                   | 100                    | 68.3                 | 98.2               | 51.8      | 71.7       |
| Sungai Nibong    | 100             | 2.0                  | 46.6                   | 100                    | 68.3                 | 92.1               | 42.1      | 71.7       |
4. Conclusion
One forest performance index was developed in this study, in which a combination from several components such as spatial, flora, fauna, soil, hydrology and carbon. A total of seven indicators have been selected to produce a single index for assessing the quality of mangrove forests in this country. By utilizing geospatial and remote sensing data, an approach in assessing forest quality at landscape level is becoming possible.

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