Dynamics of Carbon Stock at Selected Primary Linkages of Central Forest Spine (CFS) Corridors in Peninsular Malaysia

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The Improving Connectivity of the Central Forest Spine Project (IC-CFS) under the United Nations of Development Programme (UNDP) funded by the Global Environment Facility (GEF) and the Malaysian Government (GOM) is aimed at increasing capacity at the Federal and State level to execute the CFS Master Plan. Currently there are 37 CFS corridors that have been identified and prescribed in the CFS Master Plan. Out of this, 17 corridors are classified as Primary Linkages (PL) and 20 as Secondary Linkages (SL), with amounted a total extent of 507,976 ha. The study areas involved three PL corridors, which summing a total area of 35,905 ha, which are PL-1 in Pahang (4,355 ha), PL-2 in Perak (24,759 ha) and PL-3 in Johor (6,791 ha). Accurate assessment and efficient management of these corridors landscape require a systematic geospatial tool. The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) tool, developed by the Natural Capital Project were chosen to assess the carbon dynamics at the study areas particularly using Carbon model to determine ecosystem services and trade-offs between past (year 2010) and current (year 2020) landuse pattern in the study areas. The study found that there are changes of landuse within the corridors and thus resulted in the changes of carbon stock (C) within the ten years period. PL-1 and PL-2 showed positive increases of 23,690.34 and 830,818.10 Mg C, respectively. However, the other corridor, i.e., PL-3 indicated depletion of C at -523,484.89 Mg C between 2010 and 2020. These fluctuations were due to the conversion of forests to other land use types. Areas that indicated increased in C were undergoing protective actions and conserved the remaining forests within the corridors. The results were presented in spatially distributed maps together with the magnitude of changes. The study also discussed the potential of the InVEST tools in supporting decision making and conservation efforts in CFS and other landscapes in Peninsular Malaysia.

Keywords: Central Forest Spine, carbon, landscape corridors, geospatial, InVEST

1. Introduction

Forest fragmentation has been acknowledged as a major threat to biodiversity conservation and maintenance in the National Physical Plan (NPP), which recognizes that maintaining forest areas is critical to optimizing land use in the country. [1]. The primary basis for the Central Forest Spine (CFS) is drawn largely from Policy 19 of the National Physical Plan (NPP) which states that “A Central Forest Spine shall be established to form the backbone of the Environmentally Sensitive Area Network” and associated Measure #4 which advocates that “Studies shall be undertaken to determine the possibility of re-establishing the integrity and connectivity of forests and wetlands through the implementation of linkages between the four major forest complexes”. The main objectives of the establishment of CFS are to restore the connectivity of the forest complexes, to formulate viable land use and management guidelines for sustainable development adjacent to the Ecological Corridors identified, and to propose an effective implementation mechanism.
to execute the programs set out. It also acknowledged the multifunctional role of the forest land to be 
enhanced through the recognition of the CFS programs in creating linkages and corridors to the more 
isolated reserves. Connecting these fragmented forests is important to secure mutual co-existence and 
benefit for development and conservation.

The CFS is recognized for its population of the endangered Malayan tiger as well as being 
extraordinary rich in biodiversity in general; it also provides the country with considerable ecosystem 
goods and services and contains the water supply for most of the population on the peninsula. This 
project will conserve biodiversity and ecosystem services in three critical landscapes of the Central 
Forest Spine, by supporting the country’s CFS Master Plan to restore connectivity between forest 
complexes. It will strengthen the national and local institutional frameworks for CFS management and 
law-enforcement and support sustainable forest landscape management. It will achieve sustainability of 
funding for conservation through the diversification of funding sources and the mainstreaming of 
ecosystem service values into land-use planning.

To support the sustainable forest landscape management, a tool namely Integrated Valuation of 
Ecosystem Services and Tradeoffs (InVEST), an open-source software tool developed by the Natural 
Capital Project (NatCap) that model ecosystem services based on biophysical and economic ‘production 
functions’ was identified as the potential ICT tool to be tested in this study sites. InVEST is designed to 
help local, regional, and national decision-makers incorporate ecosystem services into a range of policy 
and planning contexts for terrestrial, freshwater, and marine ecosystems, including spatial planning, 
strategic environmental assessments, and environmental impact assessments [2]. InVEST models are 
spatially explicit, using maps as information sources and producing maps as outputs. InVEST returns 
results in either biophysical or economic terms.

This study aims at evaluating the ecosystem services in target forest landscape. InVEST was used as 
a tool for the valuation. Carbon model, which is one of the models available in InVEST was used to 
assess carbon stock at three ecological corridors, which are which are Primary Linkage 1 (PL-1) in 
Pahang (4,355 ha), PL-2 in Perak (24,759 ha) and PL-3 in Johor (6,791 ha). Overall, the study can be 
linked to the 13th and 15th goals under United Nations (UN) Sustainable Development Goals (SDGs), 
which are Climate Change and Life on Land, respectively.

2. Methodology

2.1 The Study Sites

In this study, Primary Linkages has been identified in areas where it is crucial to re-establish forest 
connectivity to achieve the main CFS link. Selected PLs for this study are connecting several Permanent 
Reserve Forests (PRF), which are: (i) CFS1-PL-1: Tanum FR (Greater Taman Negara) – Sg Yu FR (Main Range), (ii) CFS1-PL-2: Temengor FR (Main Range) – Royal Belum State Park (Main Range), 
and (iii) CFS1-PL-3: Lojing FR (Main Range) – Sg Brok FR (Main Range). Location of each corridor 
is depicted in Figure 1 (a – c), respectively. Major interventions are required to establish these linkages. 
The establishment of all the PLs will lead to the formation of the Central Forest Spine (Figure 2).

2.2 Data preparation

Landuse/land cover (LULC) classification is the primary input data for this study. Besides data on 
carbon content for each LULC category was also required; this data is presented in comma separated 
value (.CSV) format with a unique landuse code assigned for each LULC class. Values of these carbon 
content were gathered from the literature, where studies have been conducted to measure carbon stock 
for each LULC class. These values were integrated with the LULC spatial data for modelling and 
changes assessment by the InVEST Carbon Model. LULC spatial data for the year 2010 and 2020 were 
produced from satellite images classification. Landsat-5 images were used for the year 2010 and higher 
resolution SPOT-7 images were used for the year 2020 over the corridors. The forested area category 
in PRFs) was further stratified according to the status of the forests based on of the 5th National Forest
Inventory (NFI-5). This stratification was conducted to ensure that the estimated carbon contents are representative to the real conditions of the forests. Unique numbers were assigned to each LULC class and were then converted into raster format using Quantum GIS (Q-GIS) software.

Carbon pools values consider above-ground, below-ground, soil, and dead organic matter of an ecological landscape. These values containing the estimated values of carbon contents for each landuse class, and each was acquired from the previous studies [e.g., 3 – 5]. These values were applied in the Carbon Model to produce the total carbon estimates of each LULC class. Landuse/land cover classes and the corresponding values of carbon contents is summarized in Table 1.

![Figure 1 Selected CFS corridors as pilot sites in this study.](image)

2.3 Data processing

InVEST version 3.8.9 was used to evaluate the changes of carbon stock within the ecosystem existed in each corridor. The Carbon Model engaged both spatial and carbon content data to produce maps of current (2010) and future (2020) patterns of LULC and the total carbon stock within each corridor. All spatial data need to be in the same map projection system and the attributes must contain the landuse code corresponding to the carbon content listed in the CSV tables. InVEST Carbon Model was executed, and the results contained estimates of (i) the amount of carbon currently stored in the study site and (ii) the amount of carbon sequestered and/or emitted over a given period [6]. The monetary value of the ecosystem service can be estimated using data on the market or social value of sequestered carbon, its annual rate of change and a discount rate, if the carbon price is available. All information is presented in a form of maps and statistics.
Figure 2 CFS corridors in Peninsular Malaysia.
Table 1 Carbon stock values assigned according to the land use classes.

| Land use code | Land use class                             | Carbon stock (Mg C ha\(^{-1}\)) |
|---------------|--------------------------------------------|---------------------------------|
|               |                                            | Above-ground | Below-ground | Soil  | Deadwood |
| 0             | No Data                                    | 0            | 0            | 0     | 0        |
| 10            | Water body                                 | 0            | 0            | 0     | 0        |
| 11            | Urban, settlement, facilities, build-up    | 7            | 0            | 35    | 1        |
| 12            | Quarry and ex-mining                       | 0            | 0            | 0     | 0        |
| 13            | Open area                                  | 1            | 0            | 10    | 0        |
| 20            | Mixed horticulture                         | 54           | 12           | 25    | 5        |
| 31            | Oil palm plantation                        | 36           | 8            | 35    | 4        |
| 32            | Rubber plantation                          | 58           | 13           | 35    | 6        |
| 33            | Orchards                                   | 125          | 29           | 115   | 13       |
| 34            | Paddy fields                               | 3            | 1            | 10    | 0        |
| 35            | Shifting cultivation                        | 54           | 12           | 25    | 5        |
| 41            | Bushes                                     | 7            | 3            | 25    | 0        |
| 42            | Grassed area                               | 3            | 1            | 25    | 0        |
| 60            | Forest plantation                          | 44           | 13           | 35    | 6        |
| 71            | Good inland forest                         | 259          | 60           | 47    | 26       |
| 72            | Moderate inland forest                      | 206          | 47           | 47    | 21       |
| 73            | Poor inland forest                         | 174          | 40           | 47    | 17       |
| 75            | Montane forest                             | 206          | 47           | 47    | 21       |
| 76            | Peat swamp forest                          | 171          | 36           | 188   | 21       |
| 77            | Mangrove forest                            | 140          | 49           | 55    | 22       |
| 78            | Other swamp forest                         | 84           | 18           | 47    | 17       |

3. Results & Discussions

3.1 Landuse Changes

Landuse types are the most prominent factor that attributed to the attenuation of carbon stock in the CFS corridors. The landscapes of the corridors are consisting of various type of LULC as listed in Table 1. Multiple stakeholders and landowners of within the boundary of these landscapes make the management of landuse activities difficult to control and monitor. That is being the biggest challenge in developing connectivity of the CFS. However, the identification and classification of landuse types within these corridors can be easy with the help from remotely sensed imagery. Hence the assessment of carbon stock and its dynamics are also not that challenging. Through this approach, management and future planning of these corridors can be strategized and implemented systematically. Agriculture crops and secondary forest areas are the dominant in the corridors, therefore conversion of these LULC types into other uses will lead to the reduction of carbon stock. If the areas are remained as vegetative areas, somehow the carbon will increase from time to time.

Figure 3 summarizes the patterns of landuse changes that have occurred between year 2010 and 2020 within the study sites. The landuse code that is labelled on each map should be cross-referenced with the assigned carbon stock value as listed in Table 1. There is no clear pattern of these changes, but obviously, large scale conversion of forests into other land uses have resulted in huge amount of carbon loss.
3.2 Carbon Stock and Changes
The study found that there are changes in the landuse within the corridors, thus resulted in the changes of carbon stock (C) within ten years period (2010 – 2020). Carbon stock in PL-1 and PL-2 increased by 23,690.34 and 830,818.10 Mg C, respectively. However, the other corridor, PL-3 indicated depletion of C at -523,484.89 Mg C between 2010 and 2020. These fluctuations were due to the conversion of forests to other land use types. In 2010, this area was dominate by secondary forest have been undergoing conversion to oil palm and forest plantation species. Other activities such as development of pasture sites for farming and sand mining attributed to the reduction of C in this site. On the other hands, areas that indicated increased in C were undergoing protective actions and conserved the remaining forests within the corridors. The results were presented in spatially distributed maps together with the magnitude of changes. These maps are presented in Figure 4 and the magnitude of changes is summarized in Table 2.

Analysis that was conducted for the study sites indicated that there is no guarantee that the carbon stock would increase within 10 years of monitoring period. Some areas, which have undergone landuse changes will reflect the levels of carbon stock within these landscapes. However, the loss in forest land could be compensated by maintaining and enhancing the quality of the remaining forest through protection and rehabilitation efforts. This seems to be possible since the CFS intervention is one of the national key performance indicators.

| Corridor | Area (ha) | Carbon Stock (2010) (Mg C) | Carbon Stock (2020) (Mg C) | Changes of Carbon Stock (2010 - 2020) (Mg C) |
|----------|-----------|-----------------------------|-----------------------------|---------------------------------|
| PL-1     | 4,355     | 1,223,541.58                | 1,251,500.36                | 23,690.34                      |
| PL-2     | 24,759    | 7,839,030.81                | 8,681,908.41                | 830,818.10                     |
| PL-3     | 6,791     | 1,368,177.11                | 846,264.55                  | -523,484.89                    |
Figure 3 Land uses in CFS corridors of the study area.
Figure 4 Dynamics of carbon stock in CFS corridors of the study area.
4. Conclusion

The dynamics of carbon stock in the selected PL corridors have been conducted in this study by using InVEST Carbon Model. The use of InVEST Carbon Model as a tool to evaluate ecosystem services in the CFS linkages enables decision makers to analyze and assess their options. The option whether to go for those that provide the most optimum benefits in long-term period or to take fast benefits from the land. InVEST Carbon Model also provides relevant platform to perform ‘business as usual’ scenario versus scientific and multi-stakeholder consultation planned scenario for comparison analysis in a better map visualization manner. LULC data can be further categorized into finer classes through implementing large scale mapping where classes such as permanent crops are classified according to succession stages, ages or quality with different values given permitting improved accuracy of the results. This study has demonstrated that ecosystem services can be estimated and InVEST is an appropriate tool to value the services. However, further study needs to be done especially on the accuracy and reliability of the results by comparing with in-situ data.

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