Modeling of nutrient retention ecosystem services in oil palm plantations in Sei Jentikar sub-watershed using ISPO policy approach

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Abstract. Indonesia already has regulations on oil palm plantations that try to maintain good ecosystem services. The regulations are contained in ISPO. However, this regulation has not been fully implemented in oil palm plantations in Sei Jentikar sub-watershed. In this paper, we identify land cover and model N and P nutrient retention in oil palm plantations in the current condition and when ISPO is applied in Sei Jentikar sub-watershed. The method used was land cover identification using supervised classification and rivers using DEMNAS assisted by Google Earth Pro and modeling using the InVEST device. The identification results show the existing condition of oil palm plantation land covering an area of 16 962.99 ha. Meanwhile, when ISPO is applied in the oil palm plantation, the area that cannot be planted is 956.43 ha. This area has a predicted yield of around 2 226.41 tonnes/ha/year. Nutrient retention modeling results in N and P nutrient exports in existing conditions which will increase when approaching the river. Meanwhile, when scenario 2 is implemented, the export of nutrients will decrease in the buffer river. This shows scenario 2 can maintain ecosystem services nutrient retention, but will result in a reduction of value from oil palm production.

1. Introduction

In the last decade, the oil palm plantation is believed to be a business that is not environmentally friendly, because it is related to the contribution of decreasing ecosystem services (ES) functions such as decreasing soil and water quality [1,5]. On the other hand, the ES concept is currently starting to get a lot of attention from stakeholders who are trying to assess the impact of environmental changes on humans and people's welfare, with no exception to the oil palm plantation business [6,7]. This, considering the condition of the ecosystem is an important part of the assessment to be considered, because it can determine the capacity of an ecosystem to produce various kinds of fundamental human needs. In practice, ES studies should be quantified and mapped to identify risks, impacts, and potential trade-offs associated with predicting environmental change. To achieve this assessment, a variety of methods and tools have been developed to map, measure, and assess ES provision [8,10].

One of the research concerns in the concept of ES recently is the modeling of ES nutrient retention of Nitrogen (N) and Phosphorus (P). There is a method of modeling ES nutrient retention of N and P which can quantify the nutrient retention and loss of leaching, this model can be analyzed using the
InVEST device. The data from this modeling can provide important information for land managers and policymakers to evaluate the potential impacts of technical land management options. Modeling of N and P nutrient retention has now become a widely used method around the world at various spatial scales. Several examples of their use have been used to compare the advantages and disadvantages of the three types of ES models [11]. ES quantification using the InVEST nutrient delivery ratio model in Georgia, United States [12], a national scale evaluation of the nutrient retention model using the InVEST tool in the UK [13].

Currently, Indonesia already has an oil palm plantation regulation that tries to maintain ES nutrient retention. The regulation is contained in the Regulation of the Minister of Agriculture of the Republic of Indonesia No. 11 of 2015 on Indonesian Sustainable Palm Oil Certification System/ISPO. The regulation is a prohibition on clearing land and planting oil palm or making conservation areas 50 m on either side of the river. However, this regulation has not been fully implemented in oil palm plantations in Indonesia, for example in the Sei Jentikar sub-watershed. Oil palm plantations in the Sei Jentikar sub-watershed area are currently a popular income sector among the community, private, and government.

The condition of the Sei Jentikar Sub-watershed area before becoming oil palm plantations was mostly forest and mixed garden areas which naturally maintained their ecosystem productivity because they had good nutrient retention, even though the ecosystem was in very bad weather. However, after conversion to oil palm plantations, this area has the potential to decrease production potential through decreasing soil fertility quality and even potentially reducing surface water quality. This is because oil palm plantation activities require nutrient input through a very intensive application of fertilization, which can cause soil compaction due to the harvesting process and can reduce soil biodiversity. This cause will be a triggering factor for relatively high nutrient leaching and decreased ES nutrient retention, which will potentially reduce surface water quality.

Based on the conditions stated above, modeling of N and P nutrient retention in oil palm plantations in the Sei Jentikar Sub-watershed is needed. This modeling can be done using two scenarios, scenario 1 uses the land cover of existing oil palm plantations, and scenario 2 uses the Regulation of the Minister of Agriculture of the Republic of Indonesia No. 11 of 2015 concerning ISPO implemented in the Sei Jentikar sub-watershed. The purpose of this study was to identify the land cover of oil palm plantations and to model N and P nutrient retention using InVEST conditions for oil palm plantations in scenarios 1 and 2 in the Sei Jentikar sub-watershed. This research is expected to be able to evaluate the management of oil palm plantations and can be a relevant consideration to determine oil palm plantation management strategies that can minimize the decrease in ES nutrient retention of N and P.

2. Material and methods
2.1. Research area, time, tools, and material
The research area was conducted in the Sei Jentikar sub-watershed (figure 1). Meanwhile, the research was carried out in the Sei Jentikar watershed, Jambi and Bogor Regency, West Java. This research was conducted from March 2020 - October 2020. Research tools are Arcgis 10.3, Erdas Imagine 2015, Avenza Map version 3.10.2, Garmin GPS handheld, Microsoft office 2019, and transportation equipment. The research materials are OLI8-A landsat imagery, DEMNAS, Worldclim.org rainfall data, land unit map, and literature data sourced from interviews with oil palm plantation managers, laboratory analysis, and scientific article (example: journal, proceeding, and research report).

2.2. N and P nutrient retention modeling using InVEST device
The InVEST modeling device can combine tabular and spatial data with biophysical models to measure and evaluate specific ES and has been used in a variety of studies. This research used the InVEST NDR model version 3.7.0, to measure and map N and P nutrient exports to surface water flows and N and P nutrient retention in oil palm plantations in the Sei Jentikar watershed.

The InVEST model has a high sensitivity to the model to input, so it will have an impact if there is an error in entering parameters and will have a big impact on modeling. This will have an impact on the information that is incompatible with nutrient dynamics that are influenced by climate and soil. The
model will also assume that nutrients will reach the surface runoff and will have an impact on water quality at the outlet of the watershed/sub-watershed that are not suitable. Finally, the research carried out will affect the poor modeling formula study.

The data input for the InVEST nutrient retention models are as follows.  

a. Land cover map scenario 1 and 2  

The land cover in scenario 1 was obtained using the supervised classification interpretation method. Supervised classification is a classification where the analysis has a number of pixels that represent each of the desired classes or categories [13]. Meanwhile, land cover in scenario 2 is based on land cover in scenario 1 with the addition of river and river buffer interpretation. The river interpretation is carried out based on DEMNAS data as the main data. The data is processed using the Arcgis 10.3 application to determine the direction of water flow in general into two classes. Furthermore, the DEMNAS processed results are validated using the Google Earth Pro tool so that the interpretations carried out are more representative of the actual conditions. River interpretation is carried out separately and differs from the supervised classification because in the field conditions many rivers are under the canopy and have a width of <15 meters. This condition is not possible if the classification method is carried out using the supervised classification method of Landsat image because the processed Landsat image has a resolution of 15 meters × 15 meters after being processed using sharpening. Meanwhile, the classification process of oil palm plantations that must be conserved is based ISPO (scenario 2) conducted using the intersect and buffer (method) from the river using the Arcgis 10.3 device. The buffer method is used to determine the river buffer that must be conserved with a distance of 50 meters from the left and right of the river. The intersect method is carried out to determine the extent of oil palm plantations that must be conserved.

Accuracy evaluation is used to see the level of error that occurs in the sample area classification, so that the percentage of mapping accuracy can be determined. This evaluation tests the visual accuracy of the supervised classification. The accuracy test was analyzed using
the Kappa accuracy test. According to Jaya (2014), currently, the recommended accuracy is kappa accuracy, this kappa accuracy is often referred to as the kappa index.

b. Sei Jentikar sub-watershed data

Sei Jentikar sub-watershed data is obtained from processing the Digital Elevation Model (DEM) data using the Arcgis 10.3 device. The sub-watershed map obtained is the scope of the research area boundaries.

c. Digital elevation model (DEM)

The Digital Elevation Model (DEM) data used is the image of the National DEM (DEMNAS) which comes from the portal of the Geospatial Information Agency in Indonesia. DEMNAS is built from several data sources including IFSAR (5 m resolution), TERRASAR-X (5 m resolution) and ALOS PALSAR (11.25 m resolution) data, by adding the stereo-plotting Masspoint data. DEMNAS spatial resolution is 0.27-arcsecond and uses the EGM 2008 vertical datum [16]. DEMNAS functions as a determinant of the direction of surface water flow because DEMNAS can calculate the spatial height and slope of each pixel.

d. Rainfall (potential proxy of nutrient runoff)

The InVEST nutrient retention model requires a dataset showing spatial variability to calculate potential runoff in the study area which is the capacity to transport nutrients. The potential for nutrient runoff can be used in the rainfall data for the research area. Rainfall data is obtained from worldclim with a resolution of 1 km². Rainfall data is processed using the IDW (Inverse Distance Weighted) interpolation method, in order to obtain the appropriate pixel gradation and resolution (15 m × 15 m).

e. Parameters of N and P cycles in the landscape

The InVEST device model requires parameters in the form of a table and numeric data such as the Borselli kb stipulation parameter and biophysical table. The Borselli kb parameter is used to calibrate the model by determining the relationship between the model itself and hydrological connectivity. This variable describes the level of connection from ground level to watercourses [15]. In addition, the biophysical table contains information about the nutrients added for the land cover class required for each different dataset used.

The biophysical table contains data on nitrogen and phosphorus characteristics requiring nutrient load values for each land cover class (kg/ha/year). The nutrient load for each land cover was identified through interviews with oil palm plantation managers regarding the number of nutrients added to oil palm plantations using purposive sampling method and analysis of the status of N and P nutrients in palm fronds in dead stalks and literature studies [15].

In addition, the biophysical table also lists the maximum retention efficiency, critical distance, and the proportion of nutrient movement through the surface and subsurface which is nutrient transport. The maximum retention efficiency shows the percentage of nutrients that are maintained by the landscape and the value of nutrient efficiency which will be determined by the physical and chemical properties of the soil, the N and P nutrients found in plants, and the nutrients found in the fruit. The critical length is associated with land cover at their maximum nutrient retention capacity (set to pixel resolution according to each land cover dataset), and the proportion of nutrients moving through the surface and below the surface (default value is 0). If the nutrient proportion parameter is set to a value other than zero, two more parameters are added to the model: maximum subsurface retention efficiency and subsurface critical length for N and P nutrients, respectively. This parameter assumes that the soil maintains nutrients at its maximum capacity both in distance and in quantity [15].

3. Result and discussion

The interpretation of remote sensing images is the study of images with the intention of identifying the object depicted in the image and assessing the importance of the object. Interpretation is carried out as a form of the process of translating data and information about an object, area, and phenomenon in the area under study. Visual interpretation of images is done by looking at the appearance of land cover on the computer and directly in the field.
3.1. Land cover classification scenario 1 and 2

The results of land cover classification using the supervised classification method identified 5 land cover classes. This class consists of young palms, mature palms, non-oil palm shrubs, open land, non-oil palm plantations, non-oil palm roads, and built-up land as shown in figure 3. The classification results also provide the total area of each land cover class (table 1). Young palms are plantations with oil palm trees that are less than 7 years old, while mature oil palms are plantations with oil palms more than 7 years old. Based on table 1, the classification of land cover is dominated by oil palm plantations with an area of 16,962 ha (87.69%) of the total area of the sub-watershed area of Sei Jentikar 19,344 ha with a division of 2,602.35 ha as young oil palm and 14,360.63 ha as mature oil palm. This condition is because the land in the Sei Jentikar sub-watershed has become a concession area by private companies that have a focus on oil palm plantations.

**Table 1. The extent of land cover classification.**

| No | Land cover Class | Land Cover Details       | Area (ha) | Percentage Area (%) | Total Area (ha) | Percentage Total Area (%) |
|----|------------------|-------------------------|-----------|---------------------|----------------|--------------------------|
| 1  | Oil palm         | Young oil palm          | 2602.35   | 13.45               | 16962.99       | 87.69                    |
|    |                  | Mature oil palm         | 14360.63  | 74.24               |                |                          |
| 2  | Total non oil    | Shrub and open land     | 500.51    | 2.59                |                |                          |
|    | palm             | Road and built up       | 1466.74   | 7.58                | 2381.05        | 12.31                    |
|    |                  | Other plantation        | 413.80    | 2.14                |                |                          |
|    |                  | Total                   |           |                     | 19344.04       | 100.00                   |

The results of the interpretation of land cover classification have an accuracy kappa value of 0.74 (table 2). The kappa accuracy value obtained is classified as a substantial agreement or the 2nd highest group based on the accuracy suitability category [17].

![Figure 2. Map of land cover classification scenario 1.](image-url)
Table 2. Kappa accuracy class.

| Class Name                  | Kappa Accuracy |
|-----------------------------|----------------|
| Young oil palm              | 0.71           |
| Mature oil palm             | 0.71           |
| Shrub and open land         | 1.00           |
| Road and built up           | 0.86           |
| Other plantation            | 0.65           |
| Overall kappa accuracy      | 0.74           |

Meanwhile, based on scenario 2 (figure 3 and table 2), the total area of oil palm plantations that are in the river buffer and cannot be planted based on ISPO is 956.43 ha or 5.64% of the total area of oil palm plantations (16,962.99 ha). The land that cannot be planted with oil palm has significant production potential value. However, this will have a positive impact on ecosystem services, especially in terms of river water purification, considering that the Sei Jentikar sub-watershed is upstream of the Musi river and the sub-watershed of the Musi watershed. The area of the buffer river has the potential for planting palm oil ranging from 119,637 – 269,037 trees with an estimated yield of 2,226.41 tonnes/ha/year, assuming data on oil production per hectare per year is 2.62 tonnes [18].

Figure 3. Map of land cover classification scenario 2.
Table 3. Conservation area based on scenario 2.

| No | Class                  | Area (ha) | Buffer Percentage (%) |
|----|------------------------|-----------|-----------------------|
| 1  | Young oil palm cover   | 2,602.35  | 4.52                  |
| 2  | Young oil palm buffer area | 117.65   |                       |
| 3  | Mature oil palm cover  | 14,360.63 | 5.84                  |
| 4  | Mature oil palm buffer area | 838.78   |                       |
|    | Total of oil palm cover | 16,962.99 | 5.64                  |
|    | Total of the buffer area | 956.43   |                       |

3.2 Nutrient retention modeling using the InVEST tool

The objective of this model is to map watershed nutrient sources and their displacement to surface runoff. Spatial information can be used to assess nutrient retention by specific land cover. Based on figure 4, number 1 shows the general description of N nutrient exports at the study location in scenario 1, while number 2 in the figure shows when scenario 2 was applied in the study location. Furthermore, number 3 in the figure shows the general description of P nutrient exports at the study location in scenario 1, while number 4 in the figure shows the export of P nutrients when scenario 2 is applied at the study location. In figure 6 numbers 1 and 3 show the existing natural conditions and relatively river boundaries do not have a function as nutrient retention because most of the rivers around the research location are planted as oil palm plantations. Meanwhile, numbers 2 and 4, which are scenario 2, can hold the export of nutrients around the river with an area larger than the river border based on ISPO (50 meters from the left and right of the river).

One way to reduce contamination is by reducing the load or nutrient input such as fertilization. However, when this cannot be done, the ecosystem can be managed in such a way as to provide ES water purification through pollutant retention and degradation. For example, macro and micro organisms
can overcome contamination by storing it in tissues or releasing it in other forms. In addition, the soil can also absorb certain nutrients that are influenced by the properties of minerals and soil organic matter. Vegetation on river buffer lands is important, because good vegetation on the edge of the river will function as a last barrier before the dissolved nutrients and carried by water enter the surface water stream. This condition is because the river border can retain nutrients flowing from the surface or subsurface. So that the application of ISPO is predicted to reduce the export of N and P nutrients in the landscape of the research location. [19]. Based on this, scenario 2 is a recommended solution to be implemented because it can maintain nutrient retention ecosystem services. Furthermore, for the current InVEST modeling technique, the determining parameter is the difference in land cover class and nutrient load having high sensitivity.

4. Conclusion
Nutrient retention modeling using the InVEST tool is an analysis that has been widely used in the world. This condition indicates that this device is effective in quantifying nutrient retention in the landscape. The condition of oil palm plantations in Sei Jentikar Sub-watershed scenario 2 is a concept that is recommended to be implemented because the second scenario can retain nutrients better than scenario 1. Furthermore, for the current InVEST modeling technique, the determining parameter is the difference in land cover class and nutrient load having high sensitivity.

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