The use of Analytical Network Process (ANP) Approach to Assess the Health of Natural Production Forest

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Abstract. The need of the sustainable forest management has become the world most demand in a recent to face the climate change issue. Monitoring the health of forest thus should be done properly as one of indicators for achieving sustainable forest management. Forest Health Monitoring (FHM) is one of the methods applied to monitor the status, change and trends of forest health condition by using the ecological indicators. Here, we re-introduce the used of Analytical Networking Process (ANP) approach to scoring the health condition of natural production forest. We weighted the-four ecological indicators of Forest Health Monitoring (FHM), e.g. forest productivity in term of quality and quantity, forest health and vitality (tree-damage and crown condition), site quality, and biodiversity. Final score of forest health is obtained by combining indicator weights and relative score of each indicator. This work has been published in 2008, but reintroducing the method is taking a high importance as it needed for better developing the health assessment for different forest type and function.

1. Introduction
In order to have information on assessment question of the sustainability of Indonesian Tropical Rain Forest for future sustainable development, a quantitative assessment of the current and future conditions of forest resources is needed [1]. Monitoring systems to evaluate forest health should provide information on ecological status of forest, what changes are occurring and whether changes indicate a trend [2]. This information can be obtained through the implementation of periodical forest ecosystem monitoring. The USDA Forest Service, Forest Health Monitoring (FHM) is a national program designed to determine the status, changes, and trends in indicators of forest condition on an annual basis [3]. FHM Plot measurements began in New England in 1990 [4] but before 1997, research activities in Forest Health Monitoring have been carried out only in the temperate forests. Indonesia is the first country conducted Forest Health Monitoring (FHM) research in tropical rain forest through a research project conducted by SEAMEO-BIOTROP in cooperation with ITTO, Ministry of Forestry of Government of Indonesia and USDA-Forest Service from 1997 – 2001 [5]. In a later, Department of Silviculture, Faculty of Forestry IPB University adopted Forest Health Monitoring as one of supporting course for undergraduate program [6].
The fourth key selected indicators in FHM have been proven to be suitable for tropical forest, e.g. production, biodiversity, vitality and health, and site quality [1]. However, health level of forest ecosystem is still being unanswered even after the implementation of FHM method. It was due to the unavailability of the integrated system that combined overall selected indicators in pointing the forest ecosystem health level [6]. Therefore, it is important to develop the appropriate method that can combine all of the FHM indicators to be a single value, based on the forest type and function.

Here, we propose the use of Analytical Network Process (ANP) approach to formulate the health value of the forest. This study takes into account natural production forest area and will be one of series comprehensive study in developing integrated forest health value based on different forest function in Indonesia.

2. Development of Forest Health Assessment Method

2.1. Pairwise Comparison and Weighting Value of Forest Health Indicators

Figure 1 showed forest health hierarchy and its indicators dependencies relationship. Every indicator of forest health is related each other. Therefore, to assess the importance of each indicator for the health of the forest, analytical networking process [7, 8] should be used.

For implementing the ANP, the dependency level between indicators is needed. The dependency level is gained from pairwise comparison between indicators. Table 1 showed pairwise comparison of each selected indicators in assessing health condition of natural production forest. Higher value on pairwise comparison indicates that the indicator giving more influence to the health of the forest.

![Forest Health Hierarchy and Indicator Dependencies](image)

**Figure 1.** Forest Health Hierarchy and Indicator Dependencies [5]
Table 1. Pairwise Comparison of Each Indicator to the Health of Natural Forest Production [5]

| Indicator     | Growth | Diversity | Damage | Crown | Site Quality | Weighting value |
|---------------|--------|-----------|--------|-------|--------------|-----------------|
| Growth        | 1/1    | 5/1       | 2/1    | 2/1   | 3/1          | 0.387           |
| Diversity     | 1/5    | 1/1       | 1/3    | 1/3   | 1/2          | 0.069           |
| Damage        | ½      | 3/1       | 1/1    | 1/1   | 2/1          | 0.212           |
| Crown         | ½      | 3/1       | 1/1    | 1/1   | 2/1          | 0.212           |
| Site Quality  | 1/3    | 2/1       | ½      | ½     | 1/1          | 0.119           |

Inconsistency Ratio: 0.0003

Final weighting for each key indicator (Table 3) obtained from multiplication of weighting value of each indicator (Table 1) and weighting value based on dependency (Table 2). Growth has the highest weighting (0.280) as better growth of the trees is becoming one of main objective of management of natural production forest. High quality timber could be obtained from the health tree without any severe damage on it. Thus, damage condition having high contribution to the health condition of natural production forest and having the second highest weighting score (0.274).

Final weighting score of 0.224 for crown condition showed the importance of crown condition on the achievement of health condition of the forest. Crown condition and structure affected tree growth. Healthy of the crown with its wide and dense may accelerated the growth of the trees through its contribution to photosynthesis processes. Damage condition and crown condition reflected the health condition of the tree and having strong relation with tree growth.

Table 2. Weighting Value for Each of Indicator Based on its Dependency [5]

| Indicator     | Growth | Diversity | Damage | Crown | Site Quality |
|---------------|--------|-----------|--------|-------|--------------|
| Growth        | 0.000  | 0.070     | 0.368  | 0.368 | 0.193        |
| Diversity     | 0.571  | 0.000     | 0.000  | 0.143 | 0.286        |
| Damage        | 0.667  | 0.000     | 0.000  | 0.333 | 0.000        |
| Crown         | 0.532  | 0.185     | 0.185  | 0.000 | 0.097        |
| Site Quality  | 0.648  | 0.122     | 0.000  | 0.230 | 0.000        |

Table 3. Final Weighting Score for Each of Forest Health Indicator [5]

| Indicator     | Growth | Diversity | Damage | Crown | Site Quality | Final Weighting Score |
|---------------|--------|-----------|--------|-------|--------------|-----------------------|
| Growth        | 0.000  | 0.027     | 0.142  | 0.142 | 0.075        | 0.280                 |
| Diversity     | 0.039  | 0.000     | 0.000  | 0.010 | 0.020        | 0.077                 |
| Damage        | 0.141  | 0.000     | 0.000  | 0.071 | 0.000        | 0.274                 |
| Crown         | 0.113  | 0.039     | 0.039  | 0.000 | 0.021        | 0.224                 |
| Site Quality  | 0.077  | 0.015     | 0.000  | 0.027 | 0.000        | 0.144                 |

Site quality with the final weighting score of 0.144 indicated the importance of soil in providing nutrient and minerals for the tree growth. Tree biodiversity has the lowest weighting score of 0.077. However, this value indicates that biodiversity plays an important role in maintaining forest resiliency.

2.2. Indicators Scoring and Classifying

2.2.1. Tree Growth

The tree growth is assessing through the difference on basal area in two consecutive measurements. Tropical forest tree has an annual growth of 0.05 – 1.6 cm and annual basal area growth of 0.009 – 0.9 m²/ha [9, 10, 11, 12, 13]. Scoring for the tree growth is classified in Table 4.
Table 4. Scoring of Tree Growth based on Annual Basal Area Difference [5]

| Annual basal area difference (m²/ha/year) | Score |
|------------------------------------------|-------|
| ≥ 0.9                                    | 10    |
| 0.8 – 0.89                               | 9     |
| 0.7 – 0.79                               | 8     |
| 0.6 – 0.69                               | 7     |
| 0.5 – 0.59                               | 6     |
| 0.4 – 0.49                               | 5     |
| 0.3 – 0.39                               | 4     |
| 0.2 – 0.29                               | 3     |
| 0.1 – 0.19                               | 2     |
| 0.01 – 0.09                              | 1     |
| ≤ 0.0                                    | 0     |

2.2.2. Crown Condition

The crown portion of trees has always been an indicator of the health of forest trees. Five crown condition indicators used in FHM are: live crown ratio, crown density, crown dieback, foliage transparency, and crown diameter (wide and 90°) [14]. Different score is given to each of the crown condition indicators based on its value (Table 5) and summarized into one index called VCR (Visual Crown Rating) to indicate the condition of the crown. Trees crown then divided into four conditions: good, moderate, poor, and very poor [15] (Table 6). Crown condition then classified based on the VCR obtained from each trees observed (Table 7).

Table 5. Score given to Each of Crown Condition Indicators [15]

| Indicators            | Score = 1 | Score = 2 | Score = 3 |
|-----------------------|-----------|-----------|-----------|
| Live Crown ratio      | ≥ 40%     | 20 – 35%  | 5 – 15%   |
| Crown Density         | ≥ 55%     | 25 – 50%  | 5 – 20%   |
| Foliage Transparency  | 0 – 45%   | 50 – 70%  | ≥ 75%     |
| Dieback               | 0 – 5%    | 10 – 25%  | ≥ 30%     |
| Crown Diameter        | ≥ 10,1 m  | 2,5 – 10 m| ≤ 2,4 m   |

Table 6. VCR Score [15]

| VCR Score | Criteria |
|-----------|----------|
| 1 (Good)  | All of crown condition indicators have the score of 1, or only 1 indicator have the score of 2; no indicator have the score of 3. |
| 2 (Moderate) | More combination of score 1 and 2, or all have the score of 2; but none of indicators have the score of 3 |
| 3 (Poor)  | At least one indicator have the score of 3, but not all of them |
| 4 (Very Poor) | All of crown condition indicators have the score of 3 |
Table 7. Scoring Classification of Crown Condition based on VCR [5]

| VCR      | Score |
|----------|-------|
| 4        | 10    |
| 3.60 – 3.99 | 9     |
| 3.30 – 3.69 | 8     |
| 3.00 – 3.29 | 7     |
| 2.60 – 2.99 | 6     |
| 2.30 – 2.59 | 5     |
| 2.00 – 2.29 | 4     |
| 1.60 – 1.99 | 3     |
| 1.30 – 1.59 | 2     |
| 1.01 – 1.29 | 1     |
| 1        | 0     |

2.2.3. Damage Assessment
Damage indicator comprised of type of damage (DT), location of damage (DL), and severity of damage (DS). For each individual tree, a maximum of three damages can be recorded [1]. By assigning numerical values of each component, a cumulative numerical damage estimate for each tree can be developed as: damage = [xDT*yDL*zDS], where: x, y and z = weighing values based on the relative effect of each component for the growth and survival of a tree. The damage indexes divided into three levels, e.g. Tree Level Index (TLI), Plot Level Index (PLI), and Area Level Index (ALI). Formula used for TLI, PLI and ALI is as follows: TLI = [DT1*DL1*DS1] + [DT2*DL2*DS2] + [DT3*DL3*DS3], PLI = Average damage [tree1, tree2, tree3, ...], and ALI = Average damage [Cluster1, cluster2, cluster3...] [16]. Damage condition scoring is classified based on the PLI and/or ALI as follows (Table 8):

Table 8. Scoring Classification of Damage Condition based on PLI / ALI [5]

| PLI / ALI | Score |
|-----------|-------|
| 0         | 10    |
| 0.01 – 2.17 | 9    |
| 2.18 – 4.34 | 8    |
| 4.35 – 6.51 | 7    |
| 6.52 – 8.68 | 6    |
| 8.69 – 10.85 | 5    |
| 10.86 – 13.02 | 4    |
| 13.03 – 15.19 | 3    |
| 15.20 – 17.36 | 2    |
| 17.37 – 19.53 | 1    |
| 19.54 – 21.70 | 0    |

2.2.4. Site Quality
Site quality indicator is properties, function, or condition refers to the general soil health. Here, we used Cation Exchange Capacity (CEC) of the soil to obtain soil health condition (Table 9).
Table 9. Scoring Classification of Soil Health Condition based on CEC [5]

| CEC    | Score |
|--------|-------|
| ≥ 50.00 | 10    |
| 45.00 – 49.99 | 9     |
| 40.00 – 44.99 | 8     |
| 35.00 – 39.99 | 7     |
| 30.00 – 34.99 | 6     |
| 25.00 – 29.99 | 5     |
| 20.00 – 24.99 | 4     |
| 15.00 – 19.99 | 3     |
| 10.00 – 14.99 | 2     |
| 5.00 – 9.99   | 1     |
| 0 – 4.99      | 0     |

2.2.5. Trees Biodiversity

Trees biodiversity is measured using Pielou’s evenness index. The Pielou index is defined between 0 and 1, where 1 represents a community with perfect evenness, and decreases to zero as the relative abundances of the species diverge from evenness.

Table 10. Scoring Classification of Trees Biodiversity based on Pielou’s Evenness Index [5]

| Pielou Index | Score |
|--------------|-------|
| 1            | 10    |
| 0.9 – 0.99   | 9     |
| 0.8 – 0.89   | 8     |
| 0.7 – 0.79   | 7     |
| 0.6 – 0.69   | 6     |
| 0.5 – 0.59   | 5     |
| 0.4 – 0.49   | 4     |
| 0.3 – 0.39   | 3     |
| 0.2 – 0.29   | 2     |
| 0.1 – 0.19   | 1     |
| 0 – 0.09     | 0     |

2.3. Forest Health Level and Threshold

Final value of forest health level for natural production forest is obtained from the multiplication of final weighting score (Table 3) and score of each indicator. The final value of the health condition of natural production forest is formulated with:

\[
FHL = 0.280GS + 0.077DS + 0.274DgS + 0.224CS + 0.144SS \quad \ldots \quad [5]
\]

where \( FHL \) = Forest Health Level, \( GS \) = Growth Score, \( DS \) = Diversity Score, \( DgS \) = Damage Condition Score, \( CS \) = Crown Condition Score, \( SS \) = Site Quality Score

Health condition of the forest area is categorized based on the final value obtained. Ideal health condition of the forest is obtained when the value is 8 - 10, while value of 0 – 1.9 indicate extreme forest health condition in bad condition (Table 11).
Table 11. Threshold for each category of forest health condition [5]

| Threshold | Category |
|-----------|----------|
| 8 – 10    | Perfect  |
| 6 – 7.9   | Good     |
| 4 – 5.9   | Fair     |
| 2 – 3.9   | Poor     |
| 0 – 1.9   | Bad      |

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