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Community-based Bamboo Stands Management in the Kali Bekasi Watershed, Indonesia

Ni Wayan Febriana Utami[1], Hadi Susilo Arifin[2], Nurhayati HSA[2] & Syartinilia Wijaya[2]

[1] Departement of Landscape Achitecture, Faculty of Agriculture, Udayana University, Indonesia

[2] Departement of Landscape Achitecture, Bogor Agricultural University, Indonesia

Correspondence: Ni Wayan Febriana Utami Departement of Landscape Achitecture, Faculty of Agriculture, Udayana University, Indonesia. Tel: 62-361-222108. E-mail: wayan_febriana@unud.ac.id

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Abstract

A high rate of vegetation clearing around the upper stream of Kali Bekasi watershed currently causes various environmental problems, such as floods. The impacts occur predominantly in downstream area, mostly affecting cities, due to a disruption of the ecosystem in the upper stream. The main function of the upper stream to humans is acting as a buffer to protect downstream areas from flooding, run-off, as well as biodiversity protection. To achieve this, many varieties of plant are grown including bamboo plantations, which serve as a buffer plants on critical land especially with steep contours. In this study we aim to provide a better understanding of the effectiveness of different bamboo stands buffering to improve information for making management recommendation. We examine different points along the stream by mapping bamboo distribution, analyzing bamboo and non-bamboo (tree) stands diversity and biomass, and provide recommendations for bamboo management based on combining our findings with local ecological knowledge. We implemented image classification analysis for classifying bamboo and non-bamboo land use cover. We also measured bamboo and non-bamboo diversity by using Shannon's-Wienner diversity index. Our results showed that bamboo occupies approximately 5,360.89 ha or 11.39% of total area with six bamboo species. The highest bamboo diversity index was in the upper part of the Kali Bekasi watershed (0.62). In contrary, the highest bamboo biomass index was found in the lower part of the upper stream of Kali Bekasi watershed (98.96 ton ha^{-1}). We also discovered about 29 species of tree (230 trees) and 27 above-ground plant species in the surveyed area. As a result of our findings, we propose a shift towards bamboo agroforestry management in a mixed garden of *talun* form, where the community implement their local knowledge on bamboo cultivation and management to maintain the bamboo. This option could improve cooperation among farmers and the local community in order to conserve bamboo and tree species diversity in harmony to local wisdom.

Keywords: agroforestry, biodiversity, local ecological knowledge (LEK), sustainable management

1. Introduction

The upper stream of Kali Bekasi watershed is located in Mt. Pancar which is adjacent to Ciliwung watershed, West Java, Indonesia. This area has a high rate of land use change, 30.36% of agricultural land for the past 33 years (DCK of Bogor Regency, 2010). This land use change causes many environmental problems such as floods and damage to the downstream, especially the city of Bekasi in 2002, 2005 and 2007 (Tadri, 2008). Floods which impact the downstream areas are caused by the condition of the upper stream, especially reducing of vegetation coverage. Therefore, the status of the upper stream region as a buffer zone needs to be maintained, especially its biodiversity that will enhance the resilience of the area to cope with many environment challenges (Chapin III, 2000).

In addition to the importance of the buffer one for protecting downstream areas, there are several reasons to maintain the upper stream area. One of these is biodiversity. Being nominated as the third largest of genetic resources in the world, Indonesia need to conserve its biodiversity. Bamboo is an important part of Indonesia's biodiversity. Approximately 1,030 species of bamboo, belonging to 77 genera, occur globally. A total of 143 species of bamboo grows in Indonesia; 60 of these were spread to Java islands and nine species are endemic to the region (Widjaja, 2001).

People in Indonesia began to cultivate bamboo in the garden or house yard many centuries ago. Bamboo cultivation occurs widely and can be found as part of natural and artificial forest landscapes or community forest landscapes in rural area in most island in Indonesia (Kartodihardjo, 1997). Among villagers, the presence of bamboo plantation is important for their daily life. They utilize it widely to meet their needs i.e for building materials, household furniture, agricultural, and for social activities (Dransfield & Widjaja, 1995; Bourne, 2017). The species which were frequently used such as *bambu tali*, *bambu betung*, *bambu andong*, and *bambu hitam* (Krisdianto et al., 2007). As a result of centuries of bamboo cultivation and use, villagers have developed specialized local ecological knowledge (Darabant et al., 2016) for managing and using bamboo in the form of *talun* (Christanty et al., 1986).

Bamboo has considerable importance for both ecology and society, especially for rural society. However we need to provide information on how society in the Kalibekasi watersheed managing and utilizing their bamboo plantation based on their local knowledge so it could improved our understanding of how an ideal bamboo management can be achieved. In order to achieve this objective, we aim to (i) map land cover pattern and distribution of bamboo stands located in the upper stream of Kali Bekasi watershed; (ii) analyze the species diversity and number of bamboo and non-bamboo stands; (iii) analyze the bamboo stand management strategies and utilization based on local ecological knowledge; and finally (iv) recommend the bamboo stand management strategies that best conserve biodiversity and local ecological knowledge responding to the upper stream of Kali Bekasi watershed.

2. Method

2.1 Study Area

The study site located in three administrative areas which is Bogor regency, Bekasi regency, and Depok city, West Java, Indonesia (06°26’00”-06°41’00” S, 106°49’00”-107°07’00” E). It covers an area of 47,054.50 ha with elevations ranging from 0 m to 1,647 m above sea level (m.a.s.l.). The area was dominated by flat topographic types (54.10%) which had a tropical climate type A or very humid and humid climate type B (Schmidt and Ferguson). The monthly average rainfall was 339.94 mm/year. The soil type was dominated by complex latosol type which was suitable for farming. The river used to irrigate the farm in the form of lake and dam. The area boundaries are Citarum watershed on the eastern and Ciliwung watershed on the western (Figure 1).

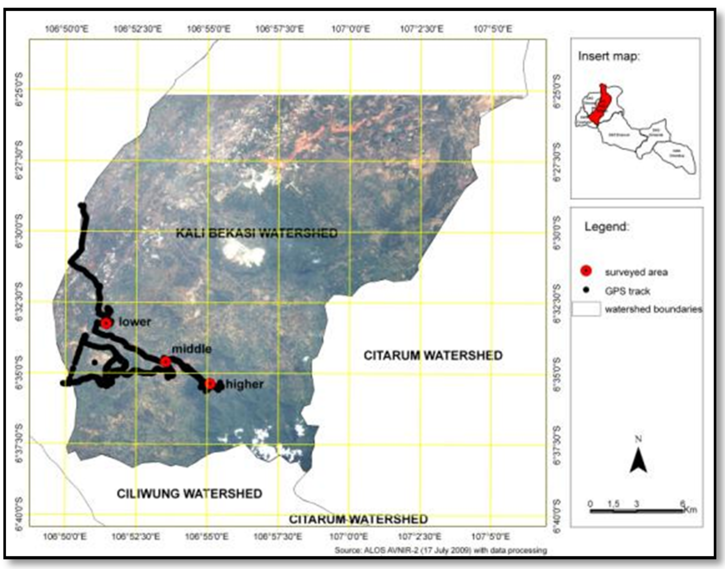

Figure 1. The study of the upper stream of Kali Bekasi watershed

The study area is limited and focused on the upper stream of Kali Bekasi watershed around Mt. Pancar. The surveyed area is divided into three locations based on elevation categories; i.e. 1) upper part (>700 m.a.s.l.) represented by *kampung Cimandala*; 2) middle part (300-700 m.a.s.l.) represented by *kampung Landeuh*; and 3) lower part (0-300 m.a.s.l.) represented by *kampung Leuwijambe*. In each location we built three observation plots of 10 m x 50 m each.

2.2 Tools and Material

Data for land cover and bamboo distribution were obtained from topographical map published by Bakosurtanal or National Survey and Mapping Agency of Republic of Indonesia on scales of 1:25,000 in sheets of 1209-141 (Ciawi area), 1209-142 (Cisarua area), 1209-143 (Bogor area), and 1209-144 (Tajur area); aerial photographs of ALOS AVNIR type 2 imagery sheets of A D1113730 0 1B2 with 10 m x 10 m of resolution were taken on 17 July 2009 by JAXA, Japan; and DEM SRTM image with 90 m x 90 m of resolution were downloaded freely in website of CGIAR-CSI Washington, US. Land cover and bamboo distribution maps were extracted, processed, and constructed using spatial software of ERDAS IMAGINE 9.1 and ArcGIS 9.3 software. Global positioning system (GPS) used for ground-truth checked during observation. To perform plant census, we used tools including diameter at breast height (dbh) meter; stationery; cameras; and interview sheets. Statistical data were processed and analyzed using MS. Excel software.

2.3 Data Collection and Classification

Plant census methods were used to collect information on the number species of bamboo, non-bamboo stands (trees) and the numbers of above-ground plants. This method included creating observation plots on the surveyed area (purposive sampling) using path and boxes-line method (Indriyanto, 2006). Three plots were set up in each surveyed area. Each plot was covered with both bamboo and tree stands in 10 m x 10 m belt-transect plot as far as 50 m. Above-ground plants were counted by setting up 2 m x 2 m plots inside of the 10 m x 10 m plots.

Focused interviews were conducted using a semi-structured method, applying a knowledge-based systems method, to collect information on the local ecological knowledge held by the community (Walker et al., 1997; Sinclair & Walker, 1999; Mulyoutami et al., 2009). We interviewed key informant people with knowledge on managing bamboo stands. These included nine people who have a role as the owner or manager of a bamboo garden.

2.4 Formulas and Analysis Approach

2.4.1 Image Analysis on Land Cover Classification

The image analysis is a two stages process. The first stage involves a pre-processing, including georeferencing and subseting of images. The secondary stage involves processing the image, including correcting and determining the training area and area of interest (AOI) by utilizing supervised classification in maximum likelihood method, accuracy assessment, and the land cover map (Figure 2).

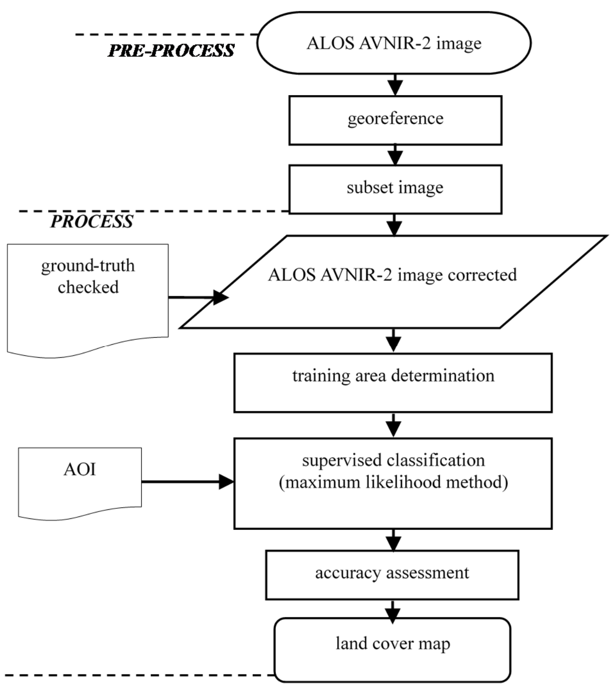

Figure 2. ALOS AVNIR-2 image processing

2.4.2 Biomass Index Analysis

Biomass index of bamboo can be calculated by looking at the relationship between dbh (D) of bamboo culms with a total dry weight of bamboo culms (B_C), bamboo branches (B_B), and bamboo leaves (B_L). Equation of bamboo biomass used in this study was the equation for 1-year-old and older clumps as follows (Saroinsong 2007):

$$B_C=0.09103(D^2)^{1.1286}$$
$$B_B=0.04469(D^2)^{0.7569} \quad (1)$$
$$B_L=0.00122(D^2)^{1.0064}$$

Tree biomass index (Y) is calculated using the dbh (D) of the tree with some constants (a,b). This equation was developed by Brown (1997):

$$Y = aD^{b*} \quad (2)$$

*a,b=the constants for tropical humid area, a=0.11; b=2.53

2.4.3 Shannon's-Wienner Diversity Index Analysis

To determine the diversity of bamboo and tree species we used Shannon's-Wienner diversity index equation (Odum, 2005).

$$H' = -\sum_{i=1}^{i=n} pi \ \log pi* \quad (3)$$

*H'=Shannon's-Wienner diversity index; pi=proportion of i-individual species with number of individuals of all types

To investigate the relationship between diversity index and an environmental factor (elevation) at three surveyed areas we performed an analysis of variance (ANOVA). This statistical analysis was done using MS. Excel software.

2.4.4 Local Ecological Knowledge Analysis

This analysis based on a list of questions related to various aspects of local knowledge as adapted from Walker et al. (1997); Sinclair and Walker (1999); and Mulyoutami (2009) with some modification on the questions. Some questions were asked including (i) background of the owner and ownership of bamboo garden (owned garden or managed garden), (ii) significance of the bamboo stands, (iii) bamboo stands management, as well as (iv) level of knowledge or role of the owner or manager in managing the bamboo garden. In addition, a set of questions were asked to identify bamboo, tree, and above-ground plant species in order to determine the use and benefits of these plants by local people. This analysis was done descriptively by addressing a list of questions on how local people utilize and benefit bamboos and trees.

3. Results and Discussion

3.1 Land Cover and Bamboo Distribution

The proportions of land cover in the upper stream of Kali Bekasi watershed based on ten land cover classes in the image analysis was: shrubs (26.38%), built areas (21.22%), plantations (13.76%), bamboo plantation (11.39%), vacant lands (7.70%), rice fields (6.04%), forest (5.57%), water bodies (3.87%), dry fields (3.37%), and clouds (0. 70%) (Figure 4). The bamboo distribution map was obtained using image analysis, showing that the 11.39% (5,360.83 ha) covered the three surveyed areas as follows; the upper part was 154.68 ha (3%), the middle part was 2,412.56 ha (45%), and the lower part was 2,793.59 ha (52%). The estimation of overall accuracy was 84.20% and Kappa accuracy was 80.69%.

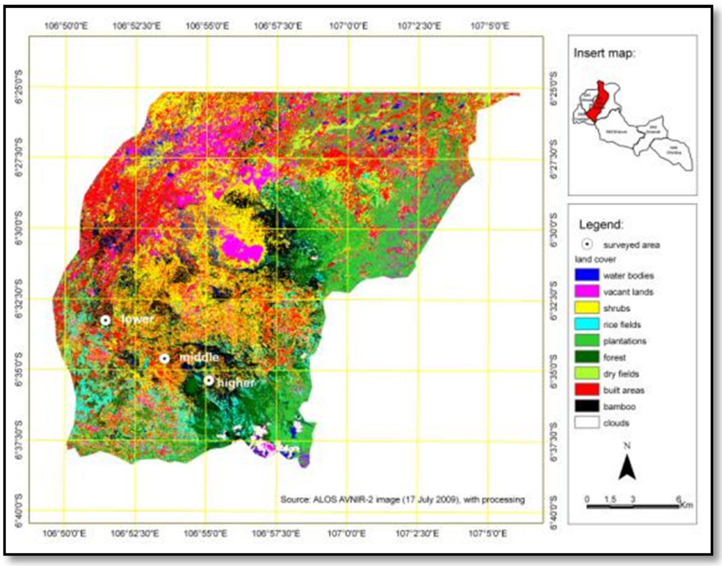

Figure 3. Land cover distribution map of the upper stream Kali Bekasi watershed

3.2 Species Diversity and Biomass Index of Bamboo Stands

Six species of bamboo found through observations on the three survey areas. These were *bambu andong* (*Gigantochloa pseudoarundiaceae* (Steudel) Widjaja), *bambu tali* (*G. apus* (Bl.Ex Schult.) F.Kurz.), *bambu hitam* (*G. atroviolacea* Widjaja), *bambu betung* (*Dendrocalamus asper* (Schult.) Backer ex Heyne), *bambu ampel hijau* (*Bambusa vulgaris* Schrad.), and *bambu krisik* (*B. tuldoides* Munro).

The diversity index in the upper part (0.62) of the surveyed area was the higher than in the middle (0.33) and lower (0.47) parts (Table 1) as it revealed by Bawer (2015) that altitude will increasing bamboo species diversity. However, the results of ANOVA test indicated that elevation does not significantly affect the bamboo diversity index (test F_{value} = 0.28<F_{table}=5.14 and p-value=0.764> critical value of 0.05).

Table 1. Bamboo diversity index in upper stream of Kali Bekasi watershed

Location		**Shannon's-Wienner diversity index (H')**	
	Plot	**Plot**	**Average**
upper	1	**0.94**	
	2	0.72	**0.62**
	3	0.20	
middle	1	0	
	2	0.99	0.33
	3	0	
lower	1	0.89	
	2	0.53	0.47
	3	0	

The total of bamboo biomass index was highest in the lower part of the study area (98.96 ton ha^{-1}), followed by the upper part of the area (79.28 ton ha^{-1}). The lowest biomass index was in middle part of the surveyed area (44.54 ton ha^{-1}) (Figure 4). The highest biomass species was found to be *bambu tali* (G. lear (Bl.Ex Schult.) F.Kurz.), which was present in as many as 139, 47 ton ha^{-1}. This value was much greater than the biomass index of other bamboo species such as *bambu ater* (G. atter (Hassk.) Kurz) with a biomass index about 45 ton ha^{-1} (Christanty et al., 1996) because this species was the most widely-utilize bamboo species in Indonesia rural society. The potential of bamboo biomass for environmental services as a carbon sink were very high i.e. 25-50% carbon content from the litter biomass and 50% carbon content from the standing biomass (INBAR, 2011).

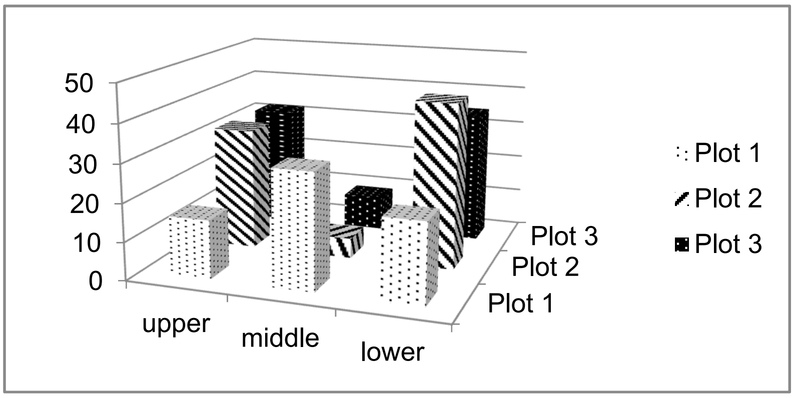

Figure 4. Bamboo biomass index in the upper stream of Kali Bekasi watershed

3.3 Species Diversity and Biomass Index of Non-Bamboo Stands

The observations of the diversity of non-bamboo stands at the three areas surveyed identified 29 species and 230 individual of plants. The species that dominated the area was banana (*Musa* spp) (119 individuals). The highest diversity index was in the upper part of the location (1.67), while in the middle and lower part respectively 1.27 and 1.21 (Table 2). The results of ANOVA test indicated that elevation did not significantly affect the non-bamboo diversity index (F_{value}=0.49<F_{tabel}=5.14 and p-value=0.636>critical value at 0.05). It is indicates that elevation difference between surveyed locations was not too significant as revealed by Karami et al. (2015) by adding slope as independent variables.

The highest potential biomass of non-bamboo stand species was in plot 3 of the middle part of the survey area, with an index value of 127 ton ha^{-1}. The lowest biomass was in plot 2 of lower part of the survey area, with an index value of 4.41 ton ha^{-1}. The total biomass produced for each location (upper, middle, lower) was as follows: 90.13 ton ha^{-1}; 248.30 ton ha^{-1}; and 14.12 ton ha^{-1} (Figure 5). We also found 27 above-ground plant species belonging to grasses, herbs, shrubs, and ferns.

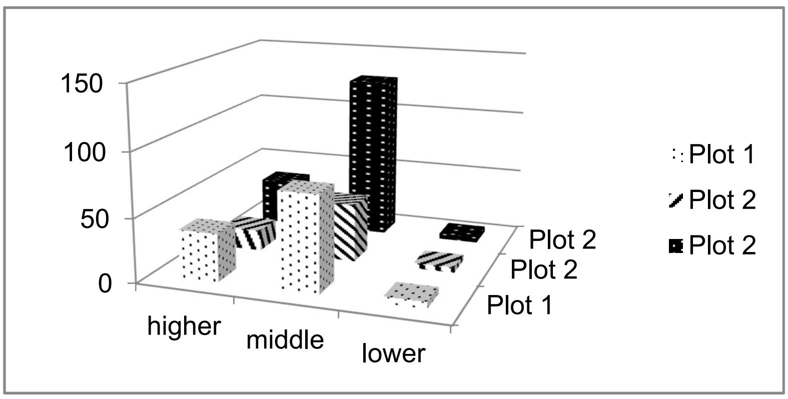

Figure 5. Non-bamboo biomass index in the upper stream of Kali Bekasi watershed

3.4 Local Ecological Knowledge (LEK)

3.4.1 Agroforestry Farming Systems

The bamboo stands found in the upper stream of Kali Bekasi watershed were implementing agroforestry farming systems in the form of mixed garden or specifically *talun* agroforestry system. Vegetation types in the mix garden included bamboo, perennial plants which producing fruits and leaves, timber which producing forestry crops, and ornamental plants. The number of plant species diversity in the garden at the three surveyed areas were as many as six species of bamboo, 29 species of non-bamboo (tree), and 27 species of above-ground plant. This value was lower than what the de Foresta et al. (2000) stated. He proposed that species richness in agroforestry of the 400 m^2 area were including 50 types of plants. The percentage of plant species occupation on each area showed as non-bamboo (tree) and above-ground plants dominance which reach 46%, 47%, and 44% respectively for trees and 40%, 45%, and 44% respectively for above-ground plants from total area (Figure 6). *Hanjuang* (*Cordyline terminalis* (L.)) were commonly used as an ornamental plant in the cemetery, which is a common Sundanese tradition.

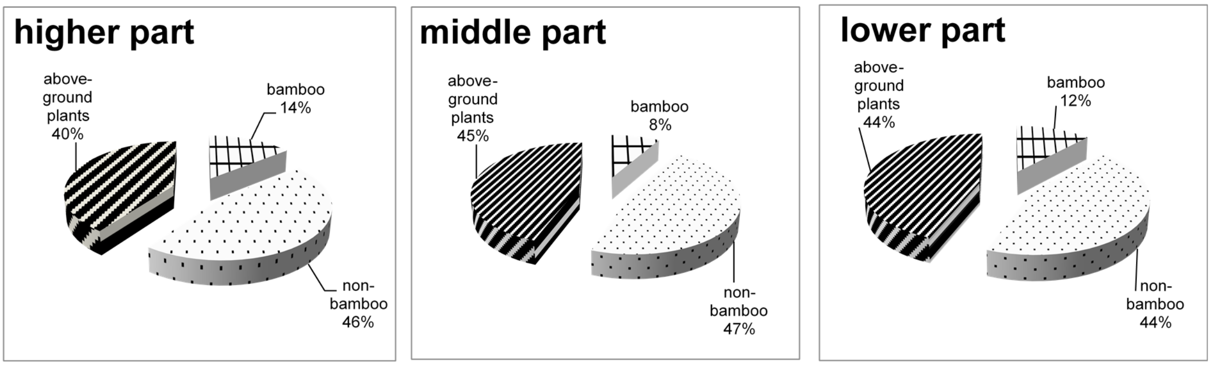

Figure 6. Species diversity in *talun* agroforestry system on each surveyed area

3.4.2 Bamboo Stands Management based on Local Ecological Knowledge

The bamboo gardens found in the upper stream of Kali Bekasi watershed are mostly implement agroforestry farming systems with mixed garden forms. Whilst the typical agroforestry practice in the rural areas of West Java called a *talun,* which similar to mixed gardens but it is very extensive management and usually far from the settlement and mostly dominated by bamboo plantation (Kosuke et al., 2014). Both mixed garden and *talun* applied complex agroforestry system.

There are four aspects were asked during the interviews with the key persons who privately owned and managed the garden. They were settled management for more than three generations. In term of ownership, the total area owned or managed in the upper part of the surveyed area was around 1,000 m^{-2} to 2,000 m^{-2}. Otherwise, in the middle and bottom area, the land ownership was less (about 1,000 m^{-2} - 1500 m^{-2} in the middle area and 300 m^{-2} - 800 m^{-2} in the lower area).

The significance of the bamboo garden based on the owner and manager perception at the three surveyed areas are mostly similar. Respondent indicated that the presence of the bamboo garden provide benefit to their daily needs such as for building and furniture materials, for agricultural and industrial equipment, as well as equipment during the funeral. They agree that the existence of the bamboo garden created cool environment, prevented a landslide, as well as maintained the quality of water resources (water springs). This findings aligned with Soemarwoto et al. (1985) discussion on *talun* significance in aspect of production (subsistence and commercial), biodiversity, and soil conservation and sustainability. The perceptions of bamboo gardens as boundaries of the land were found in the middle and lower part of surveyed area.

In term of bamboo garden management, the owner and manager in the upper part of surveyed area was carried out independently without paying for assistance, with extensive management after land clearing. In contrast, the management in the middle and lower part of surveyed area was done with intensive independent work or help of daily farming worker. The costs for the workers were amounted to IDR 15,000 to 20,000 per person per day.

The last aspect for measuring the bamboo garden management is level of local ecological knowledge (LEK). For the owner or manager bamboo garden in the upper part of surveyed area, they inherited the knowledge from their ancestor without any introduction from outside. In contrast, in the middle and lower area, they get the knowledge through agricultural extension undertaken by the government. The local wisdom of Sundanese in harvesting bamboo occurs as a guidance to harvest bamboo culms such as not cutting bamboo in the morning, when the full moon, when having bamboo shoots or flowering. It can be accepted scientifically because in that harvesting time, the quality of bamboo will decreased because it would easy to decay (Okahisa et al., 2006) or it can damage the host.

3.4.3 Scenarios on Sustainable Landscape Management of Bamboo Stands

The efforts to conserve bamboo biodiversity with local ecological knowledge need to consider some current aspects of the existence of bamboo stands in upper stream of Kali Bekasi watershed. These factors include the condition of biological diversity that exists today, the need to conserve the bamboo species diversity that already exists with the additional potential of adding new species, and the conservation of tree species, especially endemic species, and the need to cooperate between relevant stakeholders (Figure 7).

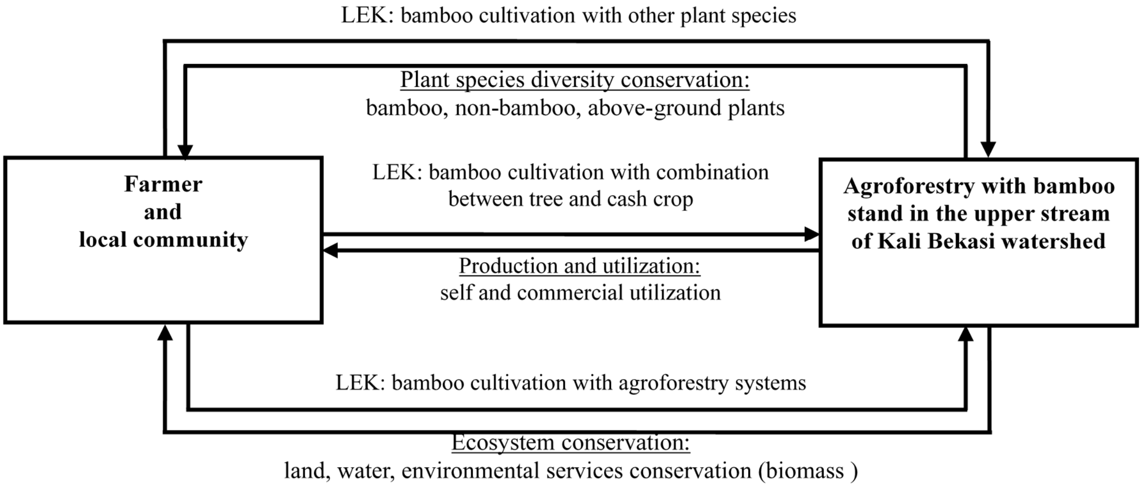

Figure 7. Proposed scenario on managing sustainable bamboo stands in the upper stream of Kali Bekasi watershed

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