Carbon stock and plants biodiversity of *pekarangan* in Cisadane watershed West Java

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Abstract. The presence of vegetation in *pekarangan* can be proposed to mitigate global climate change impacts by CO$_2$ sequestration and at the same time to promote the availability of food for the community. The aims of this research is to calculate carbon stock and biodiversity in *pekarangan*, and to compare carbon stock and biodiversity on three levels of Cisadane Watershed. Four groups of *pekarangan* defined on a purposive random sampling. Allometric models were developed to estimate aboveground biomass of vegetation, and an inventory was conducted in 48 *pekarangan*. Shannon Weiner Index ($H'$) and Margalef Index ($D_m$) are used to evaluate biodiversity, averaged 2.84 and 5.10 (G1); 2.55 and 4.27 (G2); 2.56 and 4.52 (G3); 2.68 and 4.84 (G4), while carbon stock averaged 33.20 Mg Carbon/ha (G1); 29.97 Mg/ha (G2); 59.18 Mg/ha (G3); and 40.98 Mg/ha (G4). There is no relationship between biodiversity with carbon stock on *pekarangan* ($R^2 = 0.02$), or tree’s biodiversity with carbon stock ($R^2 = 0.23$). High resolution satellite imagery can be used to extrapolate carbon stock and plants biodiversity of *Pekarangan* at watershed level.

1. Introduction

*Pekarangan* is one of traditional agroforestry systems that usually has biological, ecological, and economic interactions among the component. Its presence also important in households diet and social activities. Multistory level of vegetation structures and species richness of *pekarangan* can be promoted as supporting agricultural land for food security at the household level [1]. *Pekarangan* production contributed 11.5% of household’s income and 12.9% of household’s diet in term of food expense [2]. Biodiversity in *pekarangan* also contribute to diversification of products and diets. One of ecological functions of *pekarangan* is carbon sequestration. The existence of woody plants contribute in absorbing CO$_2$ in the atmosphere which increasing. Agroforestry pattern pure stands can absorb carbon dioxide 15.4-80.2 Mg / ha and mixture agroforestry 10.4-73.8 Mg / ha [3]. Based on these facts, existence of *pekarangan* play an important role to reduce GHGs emission, especially CO$_2$. Unlike others agroforestry systems, *pekarangan* not only sequester C in biomass and soil, but also reduce fossil-fuel burning by promoting woodfuel production, and conserve agrobiodiversity [4]. Other functions is conservation of genetic resources. The complex pattern with traditional land use systems such as tropical homegardens, have a potential to maintain high species richness and diversity.

Sequestration carbon from *pekarangan* potensial as a CO$_2$ mitigation and also build environment-friendly society. Landscape services provided by well-managed *pekarangan* will promote to establish low carbon society (LCS), means that environment friendly society and aware about concept of...
sustainability so that promote acceleration of agricultural productivity [5]. Therefore it is necessary to analyze plants biodiversity and carbon stored in pekarangan and also the correlation between them.

This study aimed to analyze and compare plants biodiversity and carbon stored in pekarangan in three levels Cisadane watershed. This watershed divided into three levels, upper stream, middle stream and downstream. Measurements carried out on those levels and then compared. Analysis of carbon stored conducted by estimation species biomass using alometric equations with different measured variables such as DBH, height, and others, while plants biodiversity analyzed with Shannon-Wiener index and Margalef index.

2. Study Site
This research site is Cisadane watershed, West Java. The objects are vegetation structures in pekarangan in upper stream, middle stream and downstream Cisadane watershed. One village were randomly selected as sample in each those levels are Tegal Waru on Ciampea district, Putat Nutug on Ciseeng district and Karawaci on Karawaci district (Figure 1).

3. Method
3.1. Sampling design for selecting pekarangan
The pekarangan samples are divided into four groups, G1, G2, G3, and G4. G1 is pekarangan size less than 120 m² with no other agricultural land (OAL), G2 is pekarangan < 120 m² with OAL, G3 is pekarangan 120 – 400 m² with no OAL and G4 is pekarangan 120 – 400 m² with OAL (Figure 2) [2]. In each village four group were selected besed on the sample frame. In total, 48 pekarangan were investigated. The consideration is the size of pekarangan and the ownership of OAL. Representative samples were collected by (1) village selection, (2) pekarangan utilization, and (3) sample frame requirement.

3.2. Data analysis
Data were gathered are biodiversity and carbon stock. Biodiversity were calculated by 2 indices: Shannon-Weinner index, and the Margalef index. Carbon stored conducted by estimation species biomass using alometric equations. These two aspects correlated by simple linear regression.
3.2.1. *Species diversity (Shannon-Wiener index).* Shannon-Wiener index is formula for calculating diversity, which combination number of species and number of individuals of each type within a community [6].

The index is thus:

\[
H' = -\sum_{i=1}^{S} (p_i \ln p_i)
\]

where \( S \) is the total number of species, and \( p_i \) is the frequency of the \( i \)th species (the probability that any given individual belongs to the species, hence \( p \)).

3.2.2. *Species richness (Margalef index).* The Margalef index is a species diversity index divided into two types of species richness (how many types are there) and assessment of species evenness or dominance (how individual species are distributed among the community). The formula of this index is [7]:

\[
D = (S - 1)\ln N
\]

where \( S \) is the number of species in a sample and \( N \) is the total individuals in pekarangan.

3.2.3. *Estimating biomass and carbon stocks.* All plants on pekarangan considered for determining above ground biomass. Trees biomass that have more than 5 cm DBH were estimated by allometric model of Chave et al. [8], while shrub generalized by allometric model of Ali et al. [9] (Table 1). The above ground carbon stock was considered as 50% of above ground biomass. Results were then scaled from Mg/plot to Mg/ha.

| Vegetation                      | Allometric model                      | Source |
|---------------------------------|---------------------------------------|--------|
| Teak (*Tectona grandis*)        | \( Y = 0.153 D^{2.39} \)              | [10]   |
| Banana (*Musa sp.*)             | \( Y = 0.0303 D^{2.1345} \)           | [11]   |
| Multispecies for shrub and trees D < 5 cm | \( \ln(AGB) = -3.50 + 1.65 \ln(D) + 0.842 \ln(H) \) | [9]    |
| Others tree                     | \( Y = 42.69 - 12.8D + 1.242D^2 \)    | [8]    |

4. Result and discussion

4.1. *Plants biodiversity in pekarangan*

There are 244 species in 76 plant families that have collected in pekarangan in Cisadane watershed with 8 functions ie ornamental plants, industrial plants, starch crops, medicinal plants, herbs, vegetables, fruit, and more. This is larger than previous studies in four watersheds West Java, namely 214 species [2], in the courtyard of Santa Rosa in the Peruvian Amazon with 168 species [12] and in homegardens of northern Thailand with 230 species [13]. However, this result is smaller than other watershed in West Java, Cianjur watershed is about 440 species [1], the western part of Kenya (253: [14]), Zaire (272: [15]) and Nicaragua (324: [16]). Overall in West Java there are 602 species [17] and nearly 40% of plants were recorded from this study.

Average Shannon Wiener index (\( H' \)) on G1 and G2 in middle stream no higher than upper stream and downstream, but overall Shannon Weinner index in middle stream Cisadane watershed has a higher value compared to other stream levels (*Figure 3*). The average \( H' \) on middle stream is 2.85; upper stream and downstream are 2.49 and 2.63. So that the number of species and their relative abundance (number of individuals of each species) are higher on middle stream. The average of Margalef index (species richness) in middle stream is higher than upper stream and middle stream 5.45, the upper stream equal to 4.15, and downstream is 4.44 (*Figure 3*). Overall pekarangan in middle stream of watershed Cisadane is more heterogeneity than others stream. Middle stream is a ecotone or intermediate region of mountain and lowland [1, 2], thats why diversity in middle stream higher than upper or downstream.
Vegetation in pekarangan can be assigned in eight use categories or usually known as horizontal diversity, consisting of ornamental plant, medicinal plant, fruit plant, vegetable crops, spice crops, industrial plants, starchy crops, and other plants like fuel wood species, wood for handicraft or wood for building materials [1]. Ornamental plants are the most common plant (50.47%), followed by fruits (23.05%), vegetables (6.17%), spices (4.05%), industrial plants (1.25%), and strachy plants (1.25%) (Figure 4). Ornamental plants identical to the unique plants morphology not only function to beautify home but also give pleasure to its owner. Some plants such as rose, jasmine and cananga used indigenous people for their activities too such as traditional weddings and traditional ceremony. Pekarangan divided into three spaces, front, sides, and back [18]. Ornamental plant commonly planted in front yard while medicinal plants, spice and vegetable crops in back or side yard. The presence of ornamental plants related to the economic status of the owner of the yard. Families with higher economic status tend to plant ornamental plants and productive plants like clove [19].
Pekarangan <120 m², G1 and G2 were combined to represent a small pekarangan, while pekarangan 120-400 m² (G3 and G4) formed a large pekarangan. In addition, G1 and G3 were combined to non-OAL group, while G2 and G4 to OAL group. The average of Shannon Wiener index on small pekarangan (H' = 2.70) tend to higher than large pekarangan (H' = 2.62) (Figure 6). However numbers of Margalef index are similar on both small and large pekarangan (4.68). Previous research [2] showed G4 is more diverse than others group.

The average of Shannon Wiener index and Margalef index (Figure 6) in non-OAL pekarangan higher than OAL pekarangan. The absence of OAL, makes homeowners take advantage of pekarangan intensively, and thats make non-OAL pekarangan more diverse. Most of the non-OAL pekarangan cultivate food, spices, and medicinal plants that can be harvested as home use or market sales. Pekarangan without other agricultural land can be used to produce carbohydrates by planting strachy crops such as cassava and sweet potatoes [20]. Furthermore, it is mentioned that the product of pekarangan also contribute to produce calories, protein, vitamin A and C [2, 21, 22]. Homeowners may sell products of pekarangan including fruits, vegetables, and timber to increase their income. The income derived from pekarangan production contributed up to 11.5 % to total income derived from the main occupations of all family members [2].

4.2. Carbon stock in pekarangan
The value of carbon stock from 48 samples pekarangan is around 0.08 Mg / ha to 131.61 Mg / ha. The average carbon stock in pekarangan in middle stream Cisadane watershed tend to higher (Figure 6), as well as number of diversity index. Overall the average is 42.11 Mg / ha, while in upper stream is equal to 33.54 Mg / ha and in downstream is 38.92 Mg / ha (Figure 7). These results are higher than the previous research in the pekarangan of Java and Sumatra (35.3-58.6 Mg / ha) [23, 24], agroforestry in Sumatra was 9 years old (14 Mg / ha) [24], and homegarden in Central Kerala, India (16-36 Mg / ha)
[15]. However these are lower than agroforestry in Sumatra over the age of 35 years (101 Mg / ha) [24] and in the traditional agroforestry Panama (145 Mg / ha) [25]. Cisadane watershed is one of northern watershed in the west part of Java. Based on previous research, the carbon stock in the northern region is lower than in the southern region (ex. Cimandiri and Cibuni watershed). It is probably because of higher intensity of pekarangan utilization from rural community in the southern region [26].

Carbon stock on small pekarangan group (28.15 Mg / ha) lower than large pekarangan group (48.23 Mg / ha) (Figure 7). Pekaran with no OAL are higher than pekarangan with OAL. The average of carbon stock on non-OAL pekarangan are 43.54 Mg / ha, while pekarangan with OAL equal to 32.84 Mg / ha (Figure 6). The number of plants per area and tree growth rate affects the amount of carbon that can be stored [27]. The structure and composition of vegetation such as type, size, height, density and age of trees may also affects the above ground carbon stock [28, 29]. Wood of slower-growing species is usually have higher specific gravity than faster-growing species, therefore the slow-growing species may accumulate more carbon in the long term [30]. Some researchers argue the existence of exotic plants related to the carbon stored in agroforestry. Local plants are more adaptable than exotic plants, because of their supposedly better adaptability to local conditions [28] besides exotic plants will be more dangerous especially if located near the conservation area [2, 29].

One of pekarangan on G3 in middle stream saving of 108.52 Mg / ha. Big trees of mango, rambutan and guava planted in this area that accounted for nearly 95.32% 103.44 Mg / ha. Tree component represented the most important C pool of the aboveground biomass of perennial plants that growing in pekarangan [27, 31]. Results from previous studies show the tree biomass potentially save 93.73% [24] and 55-81% [27] of the total carbon in above-ground.

4.3. Correlation between biodiversity and carbon stock

In tropical forests, carbon storage depends largely on species composition [32] and thus there may be exist relationship between them in agroforestry such as pekarangan. Results of linear regression between biodiversity and carbon stock is positively associated though not significant ($R^2 = 0.024$). Similarly, relationship between biodiversity and carbon stock in trees in pekarangan with $R^2 = 0.234$ (Figure 8). Variations of carbon stock does not affected by plants biodiversity. These results are consistent with several previous studies [25, 27, 33, 34]. Biodiversity can be seen as an independent pekarangan function even though C sequestration project that contribute to enhance biodiversity should be considered as more ethical in the long term than conventional afforestation project [27].

The composition of tree species and agroforestry is affects the quality and quantity of biomass on the ground and also carbon stored below ground [28]. Water availability, quality and quantity of litter, root composition, and distribution of carbon in the soil profile will influence both the quality and
quantity of the biomass returned to the soil. Recent research found a positive relationship between species richness and underground carbon biomass in the West African region [35].

Figure 8 Relation between Shannon Weinner Index and Carbon stock in pekarangan

5. Conclusion and Recommendation

Plant diversity and carbon stock are examples of landscape services, in this case is pekarangan. Landscape reviews Reviews These services can be seem optimally by the owner if pekarangan is well managed. This study bounded by watershed to minimize others environmental variables that can affect plant diversity and carbon stock data. The diversity of plant species was recorded growing in pekarangan in Cisadane watershed. Diversity indexes are higher in middle stream, as well as carbon stock. Small pekarangan (<120 m²) is more diverse, $H = 2.70; D = 4.68$. However the higher carbon stock is in large pekarangan (120-400 m²), 50.08 Mg / ha. A lot of small pekarangan are usually dominated by shrubs and grasses, while large pekarangan dominated by small and big tree which require more space. That's causes small pekarangan more diverse than large pekarangan. However large pekarangan can store more carbon because of existing trees. Non-OAL pekarangan is more diverse than OAL pekarangan ($H = 2.70; D = 4.81$) as well as carbon stock (46.19 Mg / ha). Tree component are the most contributed to above ground carbon storage. Biodiversity and aboveground carbon have a weak positive trend relationship, and thus biodiversity significantly contribute to food security while C sequestration on pekarangan contribute to mitigate CO$_2$ concentrations in atmosphere. From this study we recommend to maximize pekarangan function, plant diversity and carbon stock by planting varied plants either vertically or horizontally. These information collected here may contribute to refining broader scale methods based on remote sensing. High resolution satellite imagery can be used to extrapolate carbon stock and plants biodiversity of Pekarangan at watershed level. The further researchs may aiming at analyzing on the long term resilience of plants diversity and C sequestration, and also the potensial of below ground carbon sequestration.

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