Species diversity and carbon storage in agroforestry systems of Toraja highlands, Indonesia

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Abstract. Agroforestry practices of the Toraja highland have been developed for along time. This study determined the species diversity and carbon storage potential of the agroforestry at the high land of Toraja. A total of 30 sampling plots, 50 m × 20 m, were selected to represent different altitudes and agroforestry systems. The species diversity was analysed by identifying the constituent species in the agroforest, and biomass and carbon storage potentials of the aboveground parts were measured and analysed. Results revealed that the spatial distribution patterns of plants in the agroforestry systems were random and the selected tree species were generally related to the sites altitude. Meanwhile, the diversity species index was moderate, ranging from 1.87 to 2.14. The mean proportion of the total carbon stored in the aboveground parts for trees was 77.458 tons per ha (97.74%), litter was 1.272 tons/ha (1.61%), and undergrowth was 0.516 tons/ha (0.65%). This study contributes to the adaptation and mitigation of future climate change through the sustainable management of the highland Agroforestry systems.

1. Introduction
The Toraja Regency, South Sulawesi Province, Indonesia, is a region of high plain plateau, with a height range of 700 m to 1600 m above sea level, and is the catchment area of the Saddang watershed.

The agroforestry system that is practiced by the community is generally in the form of mixed garden [1]. The agroforestry system fulfils local demand for fire wood and food for the local community, and preserves the environmental functions of the upstream areas. Therefore, the environmental management practices in this region have a significant effect on both the quantitative and qualitative continuity of water flow to the downstream areas.

Since agroforestry practices can be modified, they are also important for climate change and biodiversity as an effective means to synergies adaptation and mitigation efforts. Furthermore, the management of the REDD+ program in the highland regions, which is an incentive scheme for agroforestry farmers, can contribute to the preservation of the ecosystem and increase of carbon reserves.

Research on the carbon storage in different land use types has been conducted in Indonesia [2] [3] [4]. However, so far there has been no discussion of carbon storage in the high plains area which has economic function and simultaneously has conservation value.

Therefore, as the representative of the highland regions a landscape-scale study of the Toraja Regency was conducted to identify the most appropriate way to maintain the potential carbon pool and to preserve and increase the carbon reserves within the framework of adaptation to and mitigation of global climate change. This study aimed to investigate the variety of species and carbon storage potential of the the agroforestry systems in the highland zone of Toraja South Sulawesi province.
2. Materials and methods

2.1. Site study background
The research was conducted in Toraja Regency, which represents the high plain plateau in South Sulawesi Province, Indonesia, at a height range of 700 m to 1600 m above sea level. The location of the plots were selected at different heights, i.e. lower physiography (700–800 m above sea level), middle physiography (1000–1100 m above sea level), and upper physiography (> 1200 m above sea level). The study was carried out for 6 months from March to August, 2017. The location of the study sites in Toraja regency is shown in figure 1.

![Figure 1. Location of the sample plots in Toraja Regency](image)

2.2. Research Materials
We measured plant biomass of the agroforests to estimate the carbon value. The plant variables observed were: (a) the structure and composition of the plant species; (b) the biomass of trees (all trees with a diameter of ≥3 cm); (c) the biomass of undergrowth (all plants with a diameter of <3 cm) [5] and (d) the necro mass (dead plants and litter).

2.3. Techniques of data collection
A total of 30 plots of 20 m × 50 m (0.1 ha) in size, were chosen according to the altitude and pattern of plant species of the agroforestry systems. Each altitude was represented by 10 sample plots. Within each sample plot, 3 subplots of 1m × 1m were used to measure the biomass of undergrowth and litter, representing dense, medium, and rare. The shape and size of the sample plots and subplots is illustrated in figure 2.

![Figure 2. The shape and size of the sample plots and subplots](image)
The primary data collected included tree diameter and height, the fresh and dry weights of the undergrowth, and the necro mass (dead plants and litter). The measurement of the plots that were categorised as ‘trees’ was conducted non destructively, while the measurement of the undergrowth was conducted destructively. Measurements of diameter and height of trees were conducted in plots of 20 m × 50 m, while fresh weights of the undergrowth and necro mass were measured in subplots. Dry weights of the undergrowth and leaf litter samples were measured in the laboratory after kiln-drying for 24 hours at a temperature of 80 °C.

2.4. Data Analysis

2.4.1. Important value index. The Important Value Index (IVI) was used to determine the composition of the species and the dominant species in a forest stand [6][7].

\[ \text{IVI} = \text{RD} + \text{RF} + \text{RDo} \] ……………………………………….(1)

where, RD is Relative Density; RF is Relative Frequency; and RDo is Relative Dominance

2.4.2. Diversity and Evenness Indices. The species diversity was measured using the Shannon-Wiener Diversity Index (H’)[21]

\[ H’ = -\sum_{i=1}^{S} p_i \ln p_i \] ……………………………………………………………(2)

where, H’= Shannon-Wiener Diversity Index, S = the number of species, \( p_i \) = the proportion of individuals or the abundance of the \( i^{th} \) species, and \( \ln \) = log base \( e \). When \( H'<1 \) = low diversity, \( H'>1 \) and <3= moderate diversity, and \( H'>3 \) = high diversity. Therefore, the higher the value of H’, the more diverse the species in the area.

The Species Evenness Index (E’) was used to determine the level of species evenness in the agroforestry area:

\[ E’ = \frac{H'}{\ln (S)} \] ………………………………………………………………………(3)

where, the \( E’ \) = Species Evenness Index, \( H’\) =Shannon-Wiener Diversity Index, and \( S \) =the number of species. When \( E’ \) is 0–<0.5 = low Species Evenness Index, and \( E’ \) 0.5–<1 = high Species Evenness Index [20]. Therefore, the higher the value of \( E’ \), the more evenly the species are distributed within the community.

2.4.3. Biomass and Carbon Estimation. The biomass of the branching trees was calculated using the allometric equation: \( W = 0.11 \rho . \text{DBH}^{2.62} \) [19], and the Arecaceae group and the necro mass of the trees without branches was calculated using: \( W = 0.25 \pi . \rho . H(D^2) \) [2]. Where, \( W\) =Biomass (tons/ha), \( \rho \)=wood density (mg/m\(^3\), kg/dm\(^3\), or g/cm\(^3\)), \( H \) = length or height of necromass or height of tree (m), \( \text{DBH} \) = Diameter Breast Height (cm), and \( D \) =Diameter of necromass or diameter of tree at breast height (cm). Biomass of other species in the plots was estimated using a specific formula [2].

The undergrowth and litter biomass were estimated using the following equation [2]:

\[ \text{DW} = \frac{\text{DWc}}{\text{FWc}} \times \text{FW} \] ……………………………………………………………(4)

Where, \( \text{DW} \) = Total Dry Weight, \( \text{DWc} \) = Dry Weight of sub samples, \( \text{FWc} \) = Fresh Weight of sub samples, and \( \text{FW} \) = Total Fresh Weight.

The value of carbon (C) storage in each agroforestry system was calculated using the conversion factor [2] [8], as follows:

\[ C = 0.46 W \] ………………………………………………………………………(5)

Where, \( C \) = carbon storage, and \( W \) = biomass.
3. Results and discussion

3.1. The composition of plant species

There was a total of 30 plant species in the community forests with an agroforestry system in the high plain area of Toraja Regency, including 8 species of wood trees for building and firewood. The majority of the trees, which were generally found in community gardens, were *Casuarina junghuhniana*, *Pinus merkusii*, *Elmerillia pubescens*, and *Palaquium obovatum* and 3 species of bamboo (*Schizostachyum brachycladum*, *Gigantochloa atter*, and *Dendrocalamus asper*).

The fruit trees, which were generally planted and occurred frequently in agroforestry system, were *Durio zibethinus*, *Lansium domesticum*, and *Nephelium lappaceum* L. The multi-purpose tree *Arenga pinnata* was also found frequently in the community gardens. The agricultural commodity species were *Coffea arabica*, *Coffea robusta*, *Syzygium aromaticum*, and *Theobroma cacao*. Other species were medicinal plants, such as *Curcuma longa*, *Alphinia galanger* (L.), and *Curcuma zanthorrhiza*, which can grow in the shade of other trees. The species composition of agroforestry constituents in the highland of Toraja Regency is shown in Table 1.

| No | SPECIES                     | PHYSIOGRAHY |
|----|-----------------------------|-------------|
|    |                             | UPPER | MIDDLE | LOWER |
| 1  | *Casuarina junghuhniana*    | √     | √       | √     |
| 2  | *Elmerillia pubescens*      | √     | √       | √     |
| 3  | *Pinus merkusii*            | -     | √       | √     |
| 4  | *Palaquium obovatum*        | √     | √       | √     |
| 5  | *Pigafetta filaris*         | √     | √       | √     |
| 6  | *Toona sureni*              | -     | √       | -     |
| 7  | *Gmelina arborea*           | -     | -       | √     |
| 8  | *Albizia falcataria*        | -     | √       | √     |
| 9  | *Arenga pinnata*            | √     | √       | -     |
| 10 | *Lansium domesticum*        | -     | √       | √     |
| 11 | *Durio zibethinus*          | √     | √       | √     |
| 12 | *Nephelium lappaceum* L.    | √     | √       | -     |
| 13 | *Garcinia mangostana* L.    | -     | -       | √     |
| 14 | *Persea americana*          | -     | √       | -     |
| 15 | *Arthocarpus integrus*      | -     | -       | √     |
| 16 | *Cocos nucifera*            | -     | -       | √     |
| 17 | *Areca catechu*             | √     | -       | -     |
| 18 | *Bambusa sp*                | √     | √       | √     |
| 19 | *Psidium guajava*           | -     | -       | √     |
| 20 | *Mangifera indica*          | -     | √       | √     |
| 21 | *Citrus mobilis*            | -     | √       | √     |
| 22 | *Musa paradisiaca*          | √     | √       | √     |
| 23 | *Coffea arabica*            | √     | √       | √     |
| 24 | *Coffea robusta*            | -     | √       | √     |
| 25 | *Syzygium aromaticum*       | -     | √       | √     |
| 26 | *Theobroma cacao*           | √     | √       | √     |
| 27 | *Spondias dulcis*           | -     | √       | -     |
| 28 | *Curcuma longa*             | -     | √       | √     |
| 29 | *Alphinia galanger*(L.)     | -     | √       | √     |
| 30 | *Curcuma zanthorrhiza*      | -     | √       | √     |

All of the plant species have the capacity to grow and develop in either high plain zones at a height of 700–1600 m above sea level. The communities arrange the plant species randomly in their gardens according to their needs.
3.2. Important Value Index (IVI)

The quantitative structure, illustrated by the Important Value Index (IVI) according to Formula 1, varied across each of the plots observed. The upstream river areas, which represented the ‘upper’ physiography, were dominated by several tree species with the highest IVI: *Casuarina junghuhniana* (76.53%), followed by *Elmerillia pubescens* (72.37%), and *Palaquium obovatum* (11.91%). The ‘middle’ physiography with the highest value of IVI was dominated by *C. junghuhniana* (82.65%), followed by *Pinus merkusii* (64.24%), and *E. pubescens* (28.17%), while the ‘lower’ physiography was dominated by *P. merkusii* (85.72%), followed by *C. junghuhniana* (57.09%), and *E. pubescens* (16.92%).

Some other species that had a moderate IVI and were usually planted by the community were *Arenga pinnata* and bamboo. Such tree species are commonly used in traditional custom activities by the Toraja community. The other constituent species had low IVI values, ranging from 1.5% to 10.0%. The highest IVI of the 6 tree species in the agroforestry system at different altitudes is shown in Table 2.

| SPECIES                      | Physiography |
|------------------------------|--------------|
|                              | Upper        |
| *Casuarina junghuhniana*     | 76.53        |
| *Pinus merkusii*             | -            |
| *Elmerillia pubescens*       | 72.37        |
| *Palaquium obovatum*         | 11.91        |
| *Syzygium aromaticum*        | -            |
| *Arenga pinnata*             | 15.42        |
| *Theobroma cacao*            | 44.86        |
| *Coffea arabica*             | 22.11        |
| *Coffea robusta*             | -            |

|                                      | Middle       |
|--------------------------------------|--------------|
| *Casuarina junghuhniana*             | 82.65        |
| *Elmerillia pubescens*               | 28.17        |
| *Palaquium obovatum*                 | -            |
| *Syzygium aromaticum*                | 20.40        |
| *Arenga pinnata*                     | -            |
| *Theobroma cacao*                    | 21.99        |
| *Coffea arabica*                     | 15.42        |
| *Coffea robusta*                     | -            |

|                                      | Lower        |
|--------------------------------------|--------------|
| *Casuarina junghuhniana*             | 57.09        |
| *Elmerillia pubescens*               | 21.62        |
| *Palaquium obovatum*                 | -            |
| *Syzygium aromaticum*                | 42.48        |
| *Arenga pinnata*                     | -            |
| *Theobroma cacao*                    | 38.52        |
| *Coffea arabica*                     | -            |
| *Coffea robusta*                     | 20.03        |

3.3. Diversity and evenness index

The diversity of the agroforestry system as calculated using (Formula 2 and 3) was categorised as moderate, with a value of 1.85–2.14, while the E’ in all of the research plots was high, with values of 0.71–0.79.

3.4. Carbon storage of aboveground agroforestry systems

The C storage of the agroforestry systems in Toraja Regency varied based on the altitude of the sample plots. The C storage in the upstream area of Saddang River, which represents the ‘upper’ physiography, was higher compared to other areas due to the greater number and higher density of tree species in this area.

3.5. The carbon Storage of Trees

Table 3 shows that the mean C storage of trees was greatest in the upstream area of the river (upper physiography), which was 87.674 tons/ha, lower in the middle part (middle physiography), and lowest in the lower physiography area (65.589 tons/ha).

The C storage in the upper physiography area was greater than that in the middle and lower areas. The greater volume of C stored in the plants in the upstream area of the river was due to the greater density and biomass of trees compared to other locations. The agroforestry systems were dominated
by the trees species that occurred at the highest density in the upstream area, which has strategic conservation value for preserving the catchment areas of the Saddang watershed.

3.6. The carbon storage of undergrowth and litter

The density of the undergrowth in agroforestry systems varied depending on the density of the stand, and was generally higher in the more open areas. This indicated that the mean amount of C stored in the undergrowth of the community forests varied.

The mean amounts of C stored in the undergrowth were 0.923, 0.361, and 0.263 tons/ha in the upper, middle, and lower locations, respectively. The mean amounts of C stored in litter (necromass) varied from 1.039 tons/ha to 1.530 tons/ha. The difference in litter C storage was mainly due to the density of the agroforestry systems. The C storage estimate for each agroforestry characteristic at different altitudes is presented in table 3.

| Physiography | Average Carbon Storage Based on Physiography Heights (ton/ha) | Total (ŷ) (tons/ha) | ŷ ± se (ton/ha) |
|--------------|-------------------------------------------------------------|---------------------|---------------|
| Upper (%)    | 87.674 0.923 1.530                                         | 90.127              | 90.127 ± 9.91 |
| Middle %     | 79.112 0.361 1.039                                         | 80.512              | 80.512 ± 10.46|
| Lower (%)    | 65.589 0.263 1.246                                         | 67.098              | 67.098 ± 6.59 |
| Mean Value   | 77.458 0.516 1.272                                         | 79.246              |               |
| Proportion (%)| 97.74 0.65 1.61                                           | 100.0               |               |

3.7. Total Aboveground Carbon Storage

The total aboveground C storage was calculated as the sum total of the C storage in trees, undergrowth, and litter. The results indicated that the total C storage of the community forests with an agroforestry system varied according to the density and the TBA of plants in the agroforest system. The agroforest systems in the upstream area of Saddang River (the upper physiography) had a total C storage of 90.127±9.91 tons/ha, followed by the middle physiography with 80.512±10.46 tons/ha C, and the lower physiography with 67.098±6.59 tons/ha C. The proportion of the total C content for each component of the agroforestry system was dominated by trees (97.74%), followed by litter/necromass with 1.61%, and undergrowth with 0.65%.

The results of this study concur with those of [9], who studied the land use system in 25-year old monocultural rubber plantations with C stores of 97 tons/ha and 74 tons/ha. However, the carbon storage in this study was higher compared to the cassava-tall grass combination with 3 rotations that had a C storage of only 36 tons/ha.

The C storage in the community forests with agroforestry systems in Toraja Regency was smaller than that reported by [10] for Bolivian tall, evergreen forests, that had 173 tons/ha C, and for various types of forests that had 155 tons/ha C, or for secondary forest in North Lampung and Jambi that had 177 tons/ha and 176 tons/ha C, respectively. Higher C storage was also reported by Delaney & Roshetko [11] for primary forest in North Lampung that had 325 tons/ha C, and for natural forest in Jambi that had 254 tons/ha C [9].
Differences in the C storage in some forest types may be caused by differences in the methods used to estimate the potential biomass for each species, and also by the location of sample plots for each type of plant community and forest. Errors in the measurement of C storage can occur via the shape and size of the sample plots, field measurements, and the use of allometric models [12] [13] [14]. Additionally, Laumonier et al. [13] stated that the difference in the number and size of sample plots was related to the accuracy of calculations.

In general, the potential C storage of the community forests with agroforestry systems in Toraja Regency was determined by the dominant tree species in each location. Similar results were found by Gintings [15] in the plantation forests, where the potential C storage per hectare varied depending on the species of plants, the plant ages, and the plant density. Furthermore, Gintings [15] reported that the C storage varied for several types of plant forest stands: stands of 6-year old *Acacia mangium* stored 91.2 tons/ha C; 14–24-year old *Pinus merkusii* stored 74.6–217.5 tons/ha C; 16–20-year old *Swietenia macrophylla* stored 64.1–166.6 tons/ha C; and 8–18-year old *Paraserianthes falcataria* stored 112.8–122.7 tons/ha C. *Tectona grandis* from 1–80 years, with varying density, stored 5.4–130.2 tons/ha C [16].

The C storage in the undergrowth in the agroforestry system in Toraja Regency was about 0.267–0.897 tons/ha, which was almost equivalent to the C storage in home gardens in North Lampung, which was 0.3 tons/ha [11], although it was smaller than that reported by Brown [10] for various forests types in Bolivia that had 2.4 tons/ha C.

In the agroforestry systems, the biomass of trees constituted the greatest proportion of the aboveground plant biomass, while the biomass of the undergrowth and leaf litter provided only a small proportion. The variation in plant biomass was determined by the number and size of the trees in the community forests [17]. This proportion becomes greater with the increasing age of the trees, as the undergrowth and leaf litter remain small while the trees grow larger. Therefore, C storage in land-use systems are influenced by the type of vegetation and the difference in wood density [8].

The development of plant diversity in agroforestry programs that can absorb C quickly and store C for a long time period can contribute to the adaptation and mitigation of climate change [18].

4. Conclusions
The diversity of the constituent species of the agroforestry systems in the highland areas of Toraja Regency was categorised as moderate, and the distribution patterns were random. There was no significant variation in species diversity in agroforestry systems at different altitudes, although there was variation in C storage at different altitudes.

The mean C storage of the aboveground plant species was dominated by trees that had 97.74%, followed by necro mass that had 1.61%, and undergrowth that had 0.65%.

The sustainable management of the agroforestry systems in high plain areas of Toraja Regency can play a role in C storage within the framework of adaptation and mitigation of climate change, as well as secure and preserve the ecological function of the catchment area of the Saddang Watershed.

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