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Plant Diversity and Aboveground Carbon Stock Along Altitudinal Gradients in Quezon Mountain Range in Southern Mindanao, Philippines

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ABSTRACT

Plant diversity, aboveground biomass, and carbon stock along portions of Quezon Mountain Range were assessed in three elevation gradients, e.g., low (400-799 m a.s.l.), middle (800-1,199 m a.s.l.), and high (1,200-1,600 m a.s.l.) in Southern Mindanao using quadrat sampling technique. A total of 146 plant species were identified including threatened Shorea contorta, Parashorea malaanonan, Dillenia philipinensis, Alstonia macrophylla, Cinammomum mercadoi, Palaqium luzoniense, Neolitsea vidalii, Dacrycarpus elatumi, and Dacrycarpus imbricatus. On the average, low diversity was recorded in all gradients particularly in low and middle elevation ranges where alteration of vegetation cover, and proliferation of bio-invasive Piper aduncum were observed. Biomass and carbon stock were largest in high elevation where the inaccessible old growth forest is located compared to a proposed mine site in low and middle elevation that are predominated by grassland, farmlands, disturbed secondary growth forest, and human settlements. Overall, carbon stocks ranged from 33.8 to 192.0 MgC ha^{-1} suggesting the good potential of the area to mitigate climate change. Sustainable management of biodiversity and carbon stock is needed by apportioning productive and protective zones in the mountain.

Key words: *biodiversity, biomass, carbon storage, disturbance, gradient*

INTRODUCTION

Forest plays a major role in biodiversity conservation and global carbon cycle because it covers 31 % of the total land area that serves as habitat to diverse flora, fauna, and microbes, and stores vast amount of carbon (*FAO 2006*). Among the forest types, tropical forest is the most diversed occupying only seven percent of the earth's land surface yet containing more than half of the planet's life forms (*Myers 1984; Wilson 1988*) and stores 428 gigatons of carbon (*Lasco 2002*). In the Philippines, 13,500 species of plants or five per cent of the world stock are found in tropical forest (*Zamora and Co 1986*). These include gigantic dipterocarp trees which are major sinks of carbon. Based on estimates, the Philippine tropical forest sequesters 107 Mt yr^{-1} CO_2, an amount that is almost equal with the country's total GHG emission (*Lasco and Pulhin 2003*). However, deforestation pushes biodiversity and carbon stocks to decline. *Hilton-Taylor* (*2000*) listed at least 321 species under the families of *Dipterocarpaceae*, *Myristicaceae*, *Euphorbiacea*, *Meliaceae*, *Leguminosae*, *Sapindaceae*, *Annonaceae*, *Apocynaceae*, *Sapotaceae*, *Lauraceae*, *Palmae*, and *Elaeocarpaceae* that are declining in population because of habitat degradation, notwithstanding unknown species that are also disappearing at unknown rates (*Pimm et al. 1995*). The Philippines lost more than 50 % of its tropical forest over the past century which accounts for at least two per cent of total global emissions from deforestation (*Lasco 1998; Sheeran 2006*). Currently, the country has about 7.2 M ha of forest cover, mostly in the mountains, left with an annual deforestation rate of 2.1 % (*FAO 2006*). Forest conversion into agriculture, legal and illegal logging, timber poaching, and mining are some of the major causes of deforestation and forest degradation (*Bankoff 2007; Liu et. al 1993*).

Reducing deforestation will help improve habitat, biodiversity, and carbon stocks. This can be achieved by replacing the drivers of deforestation with sustainable forest practices that will yield long-term ecological and economic benefits (*FPEP 2007*). For instance, incentive-based approaches such as payment for environmental service (PES), Clean Development Mechanism (CDM), and Reducing Emission from Deforestation, and Forest Degradation (REDD) can help provide alternative livelihoods and enhance ecosystem values such as food, medicine, water, ecotourism, and carbon sequestration (*Winrock International 2004, UN-REDD 2008*). However, adoption of these schemes still remains a major challenge because of limited information about the status and values of our ecosystems (*Padilla et. al. 2005; Lasco et al. 2008*). One example of which is the case of Quezon Mountain Range in Southern Mindanao that is being proposed for mining yet no assessment about its plant diversity and aboveground carbon stocks were undertaken. This study therefore aims to assess plant diversity and aboveground carbon stocks along altitudinal gradients of

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Quezon Mountain Range to determine vital ecological information for its sustainable management and biodiversity conservation.

METHODS

Study site

The study site is a portion of Quezon Mountain Range connected to Mt. Matutum Protected Landscape in Mindanao Island, Philippines (**Figure 1**). It is located at 6° 28' 55" N and 125° 03' 08" E with an area of 14,773 ha. It is bounded by three provinces namely: Sultan Kudarat (North), Davao del Sur (East), and South Cotabato (South and West). The climate belongs to Climatic Type IV of the Corona Classification System characterized by mean annual rainfall of 3078.3±420.4 mm and temperature of about 19.5±3.22 °C. Soil is generally volcanic in origin (*Pampolina et al. 2005*).

Sampling Method

Sample plots were established covering three elevation gradients, that is, low (400-799 m a.s.l.), middle (800-1,199 m a.s.l.), and high (1,200-1,600 m a.s.l.) (**Figure 2**). The low elevation is dominated by grasses and shrubs with patches of exotic, and indigenous trees where *kaingin* or shifting cultivation is common. The middle elevation is a secondary growth forest with spots of dipterocarp and non-dipterocarp stands, dense riparian zone, agroforest farms, and dominance of invasive *Piper aduncum*. The high elevation is an old growth forest that shelters climax trees such as dipterocarps, lauraceous, myrtaceous, fagaceous, and some conifers. Disturbance is minimal at this range because local communities prohibit timber cutting and farming in the area.

Standard procedure for quadrat sampling was applied

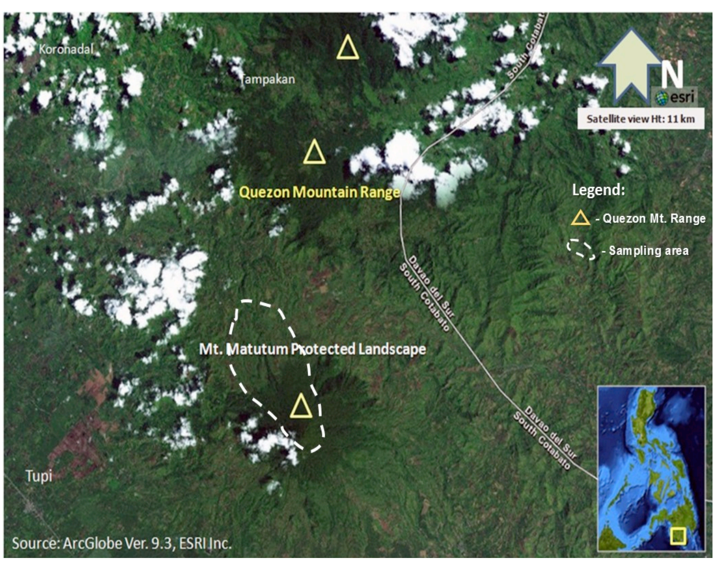

Figure 1. Satellite image of the study site in Quezon Mountain Range, Southern Mindanao.

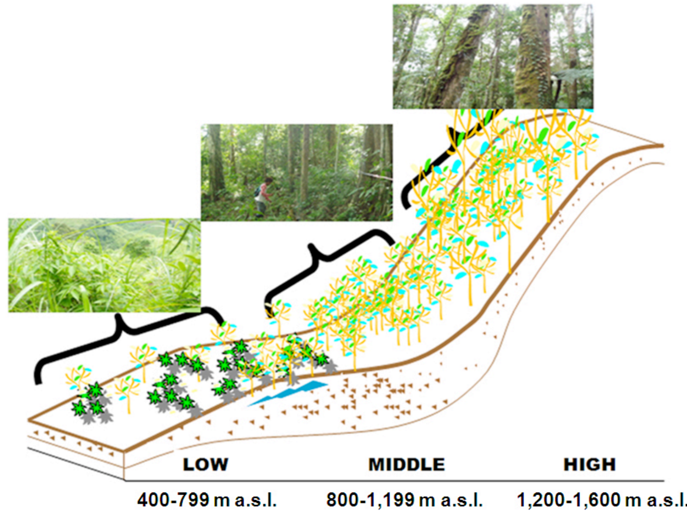

Figure 2. General view of vegetation profile of the study site (Photos by J. Pollisco).

(*Pielou 1995*). Ten sample plots measuring 10m x 10m were established along a kilometer transect in each elevation gradient. Trees with diameter-at-breast-height (DBH) greater than or equal to five cm were identified and measured. A herbarium was prepared by collecting sterile and non-sterile parts for further verification of taxa at the Museum of Natural History at the University of the Philippines Los Baños. Understory and litter samples were randomly collected within 1 m × 1 m subplots inside the 10 m × 10 m plot and were oven dried at 700 ^{o}C to constant dry weight. Elevation and location of sampling plots were obtained using Garmin eTrex H ver. 3.0.

Diversity index, biomass, and carbon stock

Species diversity index in each plot was measured using the Shannon-Wiener index (H') (*Maguran 1988*). It was interpreted using the descriptions proposed by *Fernando* (*1998*), e.g., a.) low (H'= 1.00-2.49), b.)moderate (H'= 2.50-2.90), and c.) high (H'=3.00-4.00).

Shannon-Weiner Index (H'):

$$H' = -\sum_{i=1}^{s} Pi * ln Pi$$

where s = number of species

Pi = proportion of individuals to the ith species as a portion of the total cover

ln = log base n

Tree biomass was measured using the general allometric equation developed by *Brown* (*1997*) for tropical forests with precipitation of 1500-4000 mm yr^{-1}. This equation has a correlation coefficient of R^2=0.90.

Tree biomass (kg) = 0.118 × $DBH^{2.53}$

The contribution of understory herbaceous (e.g. grasses, wildlings, weeds shrubs) and necromass (litter and fallen branches) to total biomass were determined using the following equation:

Dry mass (kg) = (subsample dry mass / subsample fresh mass) x fresh mass of whole sample

Tree carbon stock was computed by multiplying AGB with the IPCC default carbon fraction value of 50 % (*Houghton et al. 1997*). For grasses and necromass, carbon stock was computed by multiplying their respective dry mass value with 34% and 39.3% respectively, as proposed in *Lasco et al.* (*2001*). Total aboveground carbon stock was obtained by getting the sum of tree and understory carbon stocks.

Correlation test was also performed among elevation, diversity, and carbon stock to check if their values influence one another. Correlation results were tested at a significance level $p \leq \alpha = 0.05$.

RESULTS AND DISCUSSION

Floristic diversity

Reconnaissance survey of the study site listed a total of 146 plant species. By comparison, the species richness in three gradients were 52, 62, and 49 in low, middle and high elevation, respectively. These include some ecologically threatened plants based on the 2011 IUCN Red List of Threatened Species namely, *Shorea contorta*, *Dillenia philipinensis*, *Alstonia macrophylla*, *Cinnammomum mercadoi*, *Palaqium luzoniense*, and *Neolitsea vidalii* from low and middle slopes, and *Dacrycarpus elatum*, *Dacrycarpus imbricatus* from high elevation. The presence of these species indicates the need for forest conservation to maintain or enhance floristic diversity.

In terms of diversity, estimates were generally low for all gradients. Their distribution across elevation ranges followed a trend: high > middle > low (**Table 1**). In low elevation, diversity was only H'=1.50±0.31 which can be attributed to its open and disturbed condition. The presence of kaingin farms and land preparation activities for future copper mining has contributed to the removal of at least 70 per cent of the original forest cover (*Pampolina et al. 2005*). Consequently, fewer trees were accounted at this range. A similar finding was reported by *Gevaña and Pampolina* (*2008*) in Mt. Makiling, Laguna Province where diversity of the foothill (50–300 m a.s.l.) was H'=1.89. Forest cover of this gradient was also fragmented due to kaingin and expansion of settlement areas. Conversely, higher diversity was observed in the strictly protected Mt. Pangasugan (250-1100 m a.s.l.) in Leyte Province where diversity ranged from H'=2.2 to 3.9 (*Langenberger et al. 2006*).

Middle elevation has a diversity of H'=1.66±0.05. Despite a dense forest cover, only few trees tend to dominate this range particularly the bio-invasive *Piper aduncum*. *Piper aduncum* (*Piperaceae*) or *bamboo piper* is a small tree that grows from near sea level to more than 400 m gradients, with as much as 6 m in height and 10 cm diameter at breast height, and commonly distributed in West Indies, tropical South and Central America, Melanesia and Polynesia regions (*Siget et al. 2005*). *ENFOR* (*2007*) has a comparable finding on the possible detrimental effects of bio-invasive species on floristic diversity of Angat Watershed in Luzon, Philippines. In their study, diversity was found low at middle elevation gradient (600 m to 1000 m a.s.l.) where fast-growing exotic trees such as *Swietenia macrophylla* and *Gmelina arborea* predominate. Diversity of that site was H'=1.38. *Baguinon et al.* (*2003*) described that bio-invasive plants usually have allopathic mechanisms that can suppress the growth of other species.

Lastly, diversity of high elevation gradient was H'=1.84±0.11. A comparable estimate was reported by *Amoroso et al.* (*2009*) in Mt. Hamguitan, Davao Oriental (920 m to 1160 m) where diversity was only H'=1.70. Diversity of tropical mountain peaks are often low because there are few species trees that can thrive at this range, where extreme environmental condition (e.g. low temperature, high moisture, exposure to solar radiation and strong wind, and steep topography) is common (*Antonio et al. 1998; Aiba and Kitayama 1999*). Nevertheless, the diversity of this gradient was still higher compared to low and middle elevation which can be attributed to its protected condition.

Biomass and carbon stock

Tree

In low elevation, *Trema orientalis* registered the largest DBH and height with 95 cm and 30 m, respectively. Other trees that also predominated this range were *Leucaena leucocephala*, *Cocos nucifera* and *Diplodiscus suluensis*. In middle elevation, several trees exceeded 30 cm in DBH such as *Bridelia penangiana*, *Cinnamomum mercadoi*, *Dillenia philippinensis*, *Ficus magnoliifolia*, *Ficus pubinervis*, *Lithocarpus suliti*, and *Litsea glutinosa*. However, few trees also showed small diameter and height particularly the commonly listed *Piper aduncum*. Lastly, high elevation is dominated by several trees including *Ardisia darlingii*, *Crotoxylum sumatranum*, *Cryptocarya oligophlebra*, *Osmelia philippina*, *Pipturus arborescens*, and few *Lithocarpus* and *Syzigium* tree species (**Table 2)**.

In low elevation, estimates were high in Plots 3 and 7. Biomass and carbon stocks in these plots were at least 256.0 MgC ha^{-1} and 129 MgC ha^{-1}, respectively. The presence of pioneer trees such as the leguminous *Leucaena*

Table 1. Tree diversity along elevation ranges in Quezon Mountain Range.

Plot No.	Low Elevation		Middle Elevation		High Elevation	
	Diversity index *(H')*	Species richness	Diversity index *(H')*	Species richness	Diversity index *(H')*	Species richness
1	n.i.	1	1.79	6	2.16	9
2	n.i.	1	1.48	5	1.91	7
3	1.04	3	1.79	6	1.55	5
4	1.39	4	1.61	5	2.08	8
5	n.i.	0	1.79	6	1.46	5
6	2.08	8	1.61	5	n.i.	2
7	n.i.	2	1.95	7	1.97	8
8	n.i.	0	1.55	5	2.04	8
9	n.i.	0	1.61	5	1.24	4
10	n.i.	0	1.39	4	2.15	9
MEAN	1.50±0.31		1.66±0.05		1.84±0.11	

ni: no index because no. of species ≤ 2

leucocephala (33–43 cm DBH) and *Diplodiscus suluensis* (38-48 cm DBH) contributed largely to biomass and associated carbon stock production of these plots. *Schroeder* (*1992*) noted that pioneer trees can be good carbon sequesters once their frequency is enhanced. It was estimated that a seven-year old *L. leucocephala* can store at least 42 MgC ha^{-1}. *Lasco and Pulhin* (*2003*) also suggested an average of 228 MgC ha^{-1} for a mature leguminous plantation. Other additional benefits of managing pioneer trees include fuel, wood, slope stabilization, and soil enrichment during farm fallow. No tree was recorded in Plots 5, 8, 9, and 10, hence, no estimate was computed for these plots. The overall mean biomass and carbon stock in low elevation gradient were 59.6 MgC ha^{-1} and 29.8 MgC ha^{-1}, respectively (**Table 3**).

At the middle elevation, tree biomass and carbon stock were 115 MgC ha^{-1} and 57.5 MgC ha^{-1}, respectively. Values were particularly highest in Plot 4 where large trees such as *Litsea glutinosa* and *Alstonia macrophylla* were listed. This plot has a carbon stock of 127 MgC ha^{-1}. *Ficus pubinervis*, *Lithocarpus sulitii*, *Toona ciliata*, *Cinnamomum mercadoi*, and *Linociera coriacea* also contributed much to aboveground carbon.

Largest biomass and carbon stock were observed in high elevation range with 371.4 MgC ha^{-1} and 185.7 MgC ha^{-1}, respectively. Among the plots, Plot 5 registered the largest estimate with 284.3 MgC ha^{-1} owing much to the presence of *Lithocarpus* trees. Other plots also showed large carbon stocks that ranged from 52 to 284 MgC ha^{-1}. *Syzigium* trees, *Crotoxylum sumatranum*, and *Osmelia philippina* also contributed much to this range's carbon stocks.

Understory

In low elevation, more carbon is stored in herbs (3.86 MgC ha^{-1}) than in necromass (0.17 MgC ha^{-1}). This can be explained by the site's open condition where grasses, weeds, and shrubs predominate. Total carbon stock was estimated at 4 tC ha^{-1}. According to *Lasco and Pulhin* (*2003*), degraded areas such as grassland and shrub land have low capacity to accumulate carbon with only as much as 12 MgC ha^{-1}(**Table 4**).

In middle elevation, understory biomass and carbon stock were 10.9 MgC ha^{-1} and 4.3 MgC ha^{-1}, respectively. Biggest share of these values were from litter and decaying branches of about 4.28 MgC ha^{-1} (**Table 4**). Understory pools can mound to 3.7 MgC ha^{-1} (*Lasco et al. 2007*). Estimates could also differ in size depending on species composition, vegetation cover, presence of disturbance, and seasonal variations in regeneration, litter fall, and necromass decomposition (*Lorenz and Lal 2010*).

Values were largest in high elevation with a mean total biomass and carbon stock of 15.9 MgC ha^{-1} and 6.2 MgC ha^{-1}, respectively. Among the plots, Plots 4 and 5 registered the largest carbon stock with at least 11.4 MgC ha^{-1}. These values are comparably higher than the earlier estimates of *Kellman* (*1970*) and *Lasco et al.* (*2006*) for the old growth forest of Mindanao, Philippines with 2.1 MgC ha^{-1} and 1.8 MgC ha^{-1}, respectively. Such difference can be attributed to the voluminous amount of coarse woody debris that were observed in this study.

Total aboveground biomass and carbon stock

Total aboveground biomass and carbon stock is presented in **Figure 3**. Generally, estimates followed a trend of high > middle > low. High elevation has the densest biomass and carbon stocks with 192 t ha^{-1} and 387.3 MgC ha^{-1}, respectively. Overall, standing biomass of trees contributed at least 90 % in the total biomass and carbon stock indicating their significant role in carbon cycle.

Table 2. Diameter and height of trees along elevation ranges of the Quezon Mountain Range.

Scientific name	No. of trees	Mean DBH (cm)	Mean Height (m)
Low Elevation			
Cocos nucifera	1	39.0	20.0
Diplodiscus suluensis	2	43.0	16.0
Ficus variegata	1	25.0	20.0
Laportea brunea	1	5.0	7.0
Leucaena leucocephala	2	38.0	25.0
Musa acuminata	2	12.5	9.5
Trema orientalis	1	95.0	30.0
Middle Elevation			
Alstonia macrophylla	1	28.0	
Bridelia penangiana	2	40.5	21.5
Cinnamomum mercadoi	2	42.0	36.0
Cryptocarya glauciphylla	1	21.0	20.0
Cyathea sp	2	12.5.0	8.0
Decaspermum sp.	1	28.0	17.0
Dillenia philippinensis	1	60.0	37.0
Ficus magnoliifolia	1	75.0	20.3
Ficus pubinervis	2	34.0	26.8
Laportea brunea	1	5.0	5.0
Linociera coriacea	1	21.0	33.0
Lithocarpus sp.	1	22.0	14.3
Lithocarpus sulitii	1	34.0	32.0
Litsea glutinosa	2	42.2	29.7
Neonauclea calycina	1	20.0	22.0
Osmelia philippina	1	8.0	5.0
Palaquium luzoniense	1	5.0	4.0
Piper aduncum	5	5.0	6.3
Syzygium sp.	1	20.0	17.0
Thespesia populnea	1	6.0	8.0
Toona ciliata	2	19.0	11.7
Tristinopsis acutangulo	1	10.0	6.5
High Elevation			
Alstonia macrophylla	1	28.0	17.0
Ardisia darlingii	1	33.0	17.0
Astronia rolfei	1	30.0	12.7
Cinnamomum mercadoi	3	16.5	12.3
Crotoxylum sumatranum	2	46.3	23.7
Cryptocarya oligophlebra	1	35.0	26.0
Cythea contaminans	8	13.0	7.3
Decaspermum fruticosum	2	19.5	15.5
Discocalyx philippinensis	1	23.0	26.0
Ficus minnahassae	1	5.0	3.0
Ficus variegata	1	6.5	7.5
Lithocarpus sp.	8	20.8	20.1
Litsea garciae	2	21.5	21.5

Table 2. Diameter and height of trees along elevation ranges of the Quezon Mountain Range. (continued...)

Scientific name	No. of trees	Average DBH (cm)	Average Height (m)
Osmelia philippina	1	43.0	8.0
Pipturus arborescens	1	43.0	19.0
Syzigium sp.	4	36.0	18.8
Tristinopsis acutangulo	1	10.0	4.0

Table 3. Tree biomass and carbon stock along elevation range of the Quezon Mountain Range.

Plot No.	Low Elevation		Middle Elevation		High Elevation	
	Biomass (t ha^{-1})	Carbon (t ha^{-1})	*Biomass* (t ha^{-1})	Carbon (t ha^{-1})	*Biomass* (t ha^{-1})	Carbon (t ha^{-1})
1	18.51	9.26	260.99	130.50	501.95	250.97
2	18.51	9.26	23.09	11.55	466.21	233.11
3	257.99	129.00	182.52	91.26	437.90	218.95
4	0.39	0.20	253.92	126.96	474.66	237.33
5	0.00	0.00	12.16	6.08	568.54	284.27
6	41.31	20.65	144.98	72.49	163.26	81.63
7	259.13	129.56	77.38	38.69	355.31	177.66
8	0.00	0.00	104.01	52.01	98.10	49.05
9	0.00	0.00	64.42	32.21	103.26	51.63
10	0.00	0.00	26.82	13.41	545.01	272.50
MEAN	59.58	29.79	115.03	57.51	371.42	185.71
SE	33.43	16.72	29.24	14.62	57.76	28.88

Table 4. Understory biomass and carbon stock along elevation ranges of the Quezon Mountain Range.

Plot	Low Elevation				Middle Elevation				High Elevation			
	Biomass (t ha^{-1})		Carbon (t ha^{-1})		Biomass (t ha^{-1})		Carbon (t ha^{-1})		Biomass (t ha^{-1})		Carbon (t ha^{-1})	
	Herb	Necromass	Herb	Necromass	Herb	Necromass	Herb	Necromass	Herb	Necromass	Herb	Necromass
1	9.01	0.39	3.10	0.15	0.08	10.66	0.03	4.19	0.40	11.31	0.14	4.44
2	15.66	0.91	5.39	0.36	0.02	7.67	0.01	3.01	0.12	6.00	0.04	2.36
3	13.52	0.11	4.65	0.04	0.01	13.77	0.00	5.41	0.11	9.76	0.04	3.84
4	14.81	0.07	5.09	0.03	0.02	13.35	0.01	5.25	0.14	29.08	0.05	11.43
5	10.25	0.31	3.53	0.12	0.03	6.89	0.01	2.71	0.15	29.45	0.05	11.57
6	13.45	0.38	4.63	0.15	0.08	9.98	0.03	3.92	0.17	9.47	0.06	3.72
7	2.82	0.25	0.97	0.10	0.03	12.58	0.01	4.94	0.21	25.01	0.07	9.83
8	6.00	0.85	2.06	0.33	0.05	11.90	0.02	4.68	0.04	22.00	0.01	8.65
9	11.92	0.15	4.10	0.06	0.03	12.48	0.01	4.90	0.03	9.27	0.01	3.64
10	14.79	0.77	5.09	0.30	0.14	9.69	0.05	3.81	0.04	6.46	0.01	2.54
MEAN	11.22	0.42	3.86	0.17	0.05	10.90	0.02	4.28	0.14	15.78	0.05	6.20
SE	1.33	0.10	0.46	0.04	0.01	0.74	0.00	0.29	0.03	3.00	0.01	1.18
TOTAL	11.64	4.03	10.95	4.30	15.92	6.25						

Differences in the estimates among elevation ranges can be explained by two important factors. First, carbon stock is affected by density condition as seen in the species richness distribution in **Table 1**. In low elevation, the absence of trees in some plots and the abundance of grasses and agricultural crops had resulted to low carbon stock. This condition is also likely to lead to further losses in carbon stock as most of the open/grasslands are prone to grassfires during dry months (*Villamor and Lasco, 2006; Michelsen et al. 2004*). The middle elevation range is relatively denser compared with low elevation but is smaller compared with high elevation. The proliferation of bio-invasive *Piper aduncum* may have inhibited the growth and space of other trees at this range, thereby, diminishing additional carbon that could be stored by other trees. Silvicultural measures to control their population can help enhance carbon stock, such that of the high elevation where vegetation is dense and biomass was high.

Second, carbon stock is influenced by disturbance. Anthropogenic disturbances such as shifting cultivation have considerable impacts on biomass and carbon stock particularly in the low elevation gradient. The creation of gaps due to disturbances also allows the unwanted species to grow and dominate (*Oliver and Larson 1996*) as observed in the case of *Piper aduncum* in middle elevation. The long years of timber poaching coupled with natural disasters such as landslides could have been the probable reason why *Piper aduncum* has proliferated at this range. On the other hand, the protected condition of high elevation due to its inaccessibility to local people; preserved cultural value by the indigenous B'laan community; and the active forest co-management of local communities and local government are likely that led to its larger biomass and carbon stock.

Relationship between elevation, diversity and carbon stock

Elevation held as a significant factor to carbon stock with *r*= 0.55 (**Table 5**). This implies that biomass and carbon stock somehow increases as the elevation increases. This relationship is reflective of the increasing stand density and decreasing disturbance observed along gradients. On the other hand, diversity was not significantly related with elevation and carbon stock. This suggests that species composition is not affected greatly by elevation nor it influence the amount of carbon stock. A similar finding was observed by *Kirby and Potvin* (*2007*) in the tropical forest of Eastern Panama where diversity and carbon stocks were not significantly related. However, they suggested the possibility of harmonizing diversity and carbon stock by adopting species-level management. This involves careful selection and diversification of trees to be planted, that have large biomass and carbon stock. This kind of silvicultural strategy should therefore be considered by the mining firm, local government and indigenous community to effectively conserve the biodiversity and carbon stocks of Quezon Mountain Range.

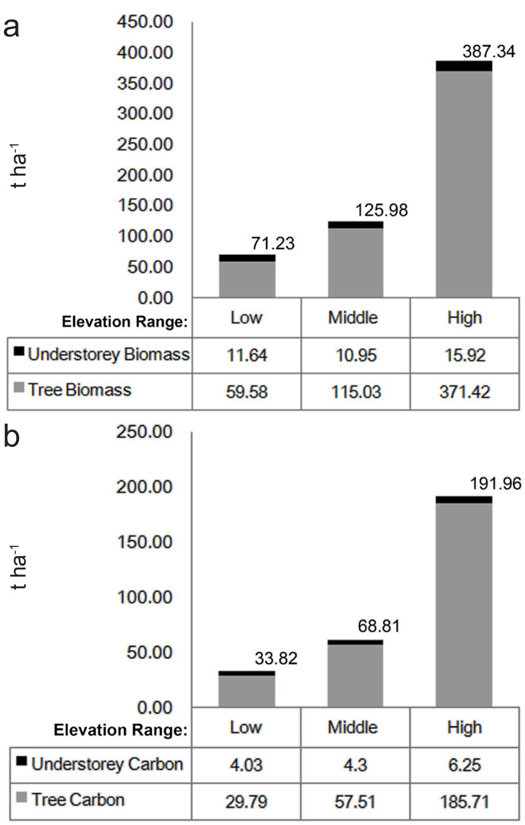

Figure 2. Total aboveground biomass (a) and carbon stock (b) along elevation ranges.

Table 5. Data showing the relationship between elevation, diversity, and carbon stock.

Parameter	*r*	*p*
Elevation (m a.s.l.) vs. Carbon stock (t ha^{-1})	0.55	0.002
Elevation (m a.s.l.) vs. Diversity (H')	0.33	0.114
Carbon stock (t ha^{-1}) vs. Diversity (H')	0.23	0.317

Conclusions and Recommendations

Plant diversity, aboveground biomass, and carbon stock along portions of Quezon Mountain Range in Southern Mindanao were assessed revealing higher values in high elevation gradient compared with low and middle gradients. Plant diversity was relatively poor from low to middle gradients which can be attributed to human disturbances particularly kaingin farming. The proliferation of bio-invasive *Piper aduncum* has also contributed to low diversity and carbon stock in the middle gradient. Carbon stock significantly increases with elevation indicating that disturbances decrease while stand density increases towards the peak. To improve the current conditions, landscape approach to forest management is recommended. This involves zoning the different gradients into productive and protective areas to provide clear boundaries for developing upland farms and protecting natural forest stands. Silvicultural measures such as enrichment planting using indigenous trees to fill-up forest gaps could also be beneficial to augment species diversity, reduce bio-invasion and enhance carbon stocks.

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