Carbon Stock in Woody Plants of Humbo Forest and its Variation along Altitudinal Gradients: The Case of Humbo District, Wolaita Zone, Southern Ethiopia

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Abstract: Forests play a critical role in the natural global carbon cycle by capturing carbon from the atmosphere through photosynthesis. However, Ethiopia does not have carbon inventories and databank to monitor and enhance carbon sequestration potential of different forests. As result, this study was conducted in Humbo forest with the overall objective of estimating the total carbon stock in woody plants and its variation along altitudinal gradients, as well as its implication for climate change mitigation. The above and below ground biomass, dead litter biomass and soil carbon were measured and estimated by using allometric equations. Trees with DBH>2.5 cm were measured for their height and diameter at breast height, and the result was analyzed by SPSS software, version 20. The findings of the study showed that *Syzgium guineese*(L.) Skeels was the most dominant and *Prunus africana* (Hook. f.) Kal was the least dominant one. The average carbon stock of the study area was 30.77, 14.46, 12.55, and 168.2 ton/ha, in above ground biomass, below ground biomass, dead litter, and soil, respectively. The variation of carbon pools between altitudinal gradient was not significant. The total maximum and minimum carbon stock estimated was 361.63 and 58.49 ton/ha, respectively, with the average value of 225.98 ton/ha. The estimated money term of carbon dioxide sequestered in one hectare was \$6087.429 USD in average. This implies that the forest managed for carbon trading (to get money) indirectly sequesters about 829.35 ton /ha, in average.

Keywords: Altitudinal Gradient, Carbon Stock Potential, DBH, Height, Woody Plants

1. Introduction

According to FAO (2010), Forest is defined as a land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use. Forests and trees absorb carbon dioxide from the atmosphere and store it as carbon. Forests store about 20-40 times carbon per unit area than most crops and most of the carbon is released into the atmosphere through deforestation (Emmanuel, 2013). Forest carbon more significantly affects bioenergy emissions when biomass is sourced from standing trees compared to residues and when less GHG-intensive fuels are displaced (Keith, 2014).

As indicated by Yitebitu Moges et al., 2010, Ethiopian forests contain about 272 million metric tons of carbon, which

is almost 83% global annual carbon emission (333) Mega tone of carbon per year. However, the carbon stored in plants can be released into atmosphere in the form of carbon dioxide during deforestation. This increases the concentration of carbon dioxide in atmosphere, which leads to the constantly changing of Earth's climate. On the other hand, this extra carbon dioxide may have a number of effects on terrestrial ecosystems, from increasing plant growth rates and biomass to modifying ecosystem composition by altering the competitive balance between species (Malhi et al., 2002).

Unlike the developed countries, Ethiopia does not have carbon inventories and databank to monitor and enhance carbon sequestration potential of different forests. Only few activities about carbon sequestration potential have been published recently. Two of these activities were conducted by

Adugna *et al.*, (2013) and Mohammed *et al.*, (2014).

Due to reason that no study has been conducted before, this study estimated the carbon stored in above ground biomass, below ground biomass, litter biomass and Soil organic carbon. Even though this study covers only very small area looking from the Ethiopian forest coverage and only small sample areas of the study site, it puts baseline information. This information can be used for the management of Humbo forest, and for further study, too.

2. Materials and Methods

2.1. Description of the Study Area

Humbo forest is located in SNNPR, Wolayta Zone Administratively, at about 420 km south of Addis Ababa (Figure 1). The elevation of the study site (with an area of 200 hectares) ranges from 1690 to 1842 meter above sea level. The rainfall in the region is between 700 and 1000mm per annum (850mm on average). Humidity is sometimes high due to cloud precipitation and local interactions between topography and weather. The mean maximum temperature lies between 18 and 24°C and mean minimum is between 12 and 15°C (Forestry Project staff and Tony Rinaudo, 2007).

Figure 1. Map of Koysha Ogodama and Ambe Shoya Kebele Forest, Humbo District.

2.2. Delineation and Stratification of the Study Area

The spatial boundaries of the study area were clearly defined and properly recognized by taking Geographical Positioning System (GPS) coordinates at each turning point to facilitate accurate measuring, accounting, and stratified in to units based on Altitude, namely lower (1690-1740), middle (1741-1791) and higher (1792-1842) m. a.s.l.

2.3. Sampling Techniques in the Field

A systematic transect sampling technique was used in this study. Parallel transects that lie with the topographic contour (parallel to the slope) of the stand were established. Eight transect lines were laid on the forest floor, that used to make sure the points or plots are distributed evenly throughout the forest stand. A compass bearing was used to allow the transects to be parallel with one another. A total of seventy

sample plots with an area of (10mx20m), each were laid along transect lines based on altitudinal variation (higher, middle, and lower) of the study area. In each plot, trees/shrubs with DBH >2.5 cm were measured for their height and diameter at breast height.

2.4. Field Carbon Stock Measurement

2.4.1. Vegetation Data Collection and Identification

The DBH and height of trees/shrubs were measured by Diameter tape and Silva-Hypsometer, respectively. The DBH of irregular trees was measured by the help of methods developed by Pearson *et al.*, (2005), and Plants were identified by using published volumes of Flora of Ethiopia and Eritrea.

2.4.2. Above and Below Ground Biomass

The above ground biomass consists of all living vegetation

above the soil, inclusive of stems, stumps, branches, bark, seeds, and foliage (Pearson et al., (2005). According to IPCC (1996), the below ground biomass is estimated as 0.47 times the above ground biomass, for tropical dry forests. In this study, this default conversion factor was used.

2.4.3. Leaf Litter (CL)

The leaf litter is defined as all dead organic surface material on top of the mineral soil. Dead wood with a diameter of less than 10 cm and greater than 2mm was included in the litter layer (Pearson et al., 2005). One rectangular sub plot of 1 m² in size was established at the center of each nested plot and the leaf litter within the 1m² sub plots was collected and weighed (both wet and fresh weight). Then after, a hundred grams (100g) fifteen representative samples were brought to the laboratory placing in a sample plastic bag and oven dried at 105⁰c to determine moisture content, from which the total dry mass was calculated (Bhishma et al., 2010).

2.4.5. Soil Organic Carbon (SOC)

Soil samples were collected from the default depth, which is 30cm (Bhishma et al., 2010) on the plots selected for litter samples. A 100 g of soil, one each from three depths (0-10 cm, 10-20 cm, and 20-30 cm) was collected from five pits in the major plot (one at the center and four at the corners of each plot) and mixed properly in their respective layers and composite sample was collected from (Figure 2). Soil samples were placed in a plastic paper bags and labeled separately. After all, the samples were taken to Wondo Genet Collage of Forestry and Natural Resources for laboratory analysis. In the laboratory, soil samples were prepared and oven-dried at 105⁰c for 24 hours to remove the soil moisture so as to determine the percentage of organic carbon and the bulk density. Then, the amount of soil organic carbon was determined.

Figure 2. Five sub-plots of soil samples inside the major plot (Area of major plot is 200m²).

2.5. Estimation of Carbon in Different Carbon Pools

2.5.1. Estimation of Above Ground Carbon (AGC) and Below Ground Carbon (BGC)

Most of allometric equations for biomass estimation are based solely on DBH (Chambers et al., 2001 and Chave et al.,

2005). However, the one, which includes height and wood density in addition to DBH, is the best (Chave et al., 2005). As a result, the equation developed by Chave et al., (2005), for tropical dry forest, was selected to estimate above ground biomass (at 5% level of confidence).

$$Y = 0.112 * (\rho D^2 H)^{0.916} \quad (\text{Equ---1})$$

Where, Y is above ground biomass, D is diameter at breast height, ρ =wood specific gravity.

$$\text{BGB} = \text{AGB} \times 0.47 \quad (\text{Equ---2})$$

Where, BGB is below ground biomass, AGB is above ground biomass, 0.47 is conversion factor. While, the multiplication factor 3.67 was used to estimate CO₂ equivalent (Pearson et al., 2007).

2.5.2. Estimation of Carbon Stocks in the Leaf Litter Biomass (LC)

According to Pearson et al., 2005, estimation of the amount of biomass in the leaf litter can be calculated by:

$$\text{LB} = \frac{W_{\text{field}}}{A} * \frac{W_{\text{(subsample, dry)}}}{W_{\text{(subsample, fresh)}}} * \frac{1}{10,000} \quad (\text{equ---3})$$

Where: LB = Litter (biomass of litter t ha⁻¹)

W_{field} = weight of wet field sample of litter sampled within an area of size 1 m² (g);

A = size of the area in which litter were collected (ha);

$W_{\text{(subsample, fresh)}}$ = weight of the fresh sub-sample of litter taken to the laboratory to determine moisture content (100g).

$W_{\text{(subsample, dry)}}$ = weight of the oven-dry sub-sample of litter taken to the laboratory to determine moisture content (g), and the total carbon content of litter (ton/ha) = Total dry litter biomass * Carbon fraction

$$C_L = \text{LB} \times \% C \quad (\text{equ---4})$$

Where, C_L is total carbon stocks in the dead litter in t ha⁻¹, % C is carbon fraction determined in the laboratory (Pearson et al., 2005). The litter carbon has to be multiplied by 3.67 to get the amount of CO₂ sequestered in the litter biomass.

2.5.3. Estimation of Soil Organic Carbon (SOC)

The soil organic carbon was calculated as recommended by Pearson et al., 2005 as follows;

$$\text{BD} = \frac{W_{\text{dry}}}{V} \quad (\text{equ---5})$$

Where, BD is bulk density of the soil sample, W_{dry} is air dry weight of soil sample, V is volume of the soil sample and it was calculated as follows;

$$V = h \times \pi r^2 \quad (\text{equ---6})$$

Where, V is volume of the soil in the core sampler auger in cm³, h is the height of core sampler auger in cm, and r is the radius of core sampler auger in cm. More over the bulk density of a soil sample can be calculated as follows:

$$\text{SOC} = \text{BD} * D * \% C \quad (\text{equ---7})$$

Where, SOC= soil organic carbon stock per unit area (t ha⁻¹), BD = soil bulk density (g cm⁻³), D = the total depth at which the sample was taken (30 cm), and %C = Carbon concentration (%)

2.5.4. Estimation of Total Carbon Stock Density

The carbon stock density was calculated by summing the carbon stock densities of the individual carbon pools of the stratum using the Pearson *et al.* (2005) formula.

$$C_T = AGC + BGC + CL + SOC \quad (\text{equ---8})$$

Where, C_T = Carbon stock density for all pools [ton ha⁻¹], AGC = Carbon in above-ground tree biomass [t C ha⁻¹], BGC = Carbon in below-ground biomass [t C ha⁻¹], CL = Carbon in dead litter [t C ha⁻¹] and SOC = Soil organic carbon..

3. Data Analysis

The data of various carbon pools measured (DBH, height, fresh weight and dry weight of litter and soil) were analyzed by

using Statistical Package for Social Science (SPSS) software version 20. Meaning, One Way ANOVA was used at 95% confidence interval.

4. Results

4.1. Species Composition

A total of 41 species having 7,389 individuals, belonging to 38 genera and 25 families were identified from Humbo forest and their carbon stock potential was estimated. Of these measured woody plant species, *Syzigium guineense* (L.) Skeels was the most dominant with recorded value of 1807 and *Prunus africana* (Hook. f.) Kalm was the least dominant species with the recorded value of 1. The maximum and minimum carbon content in a single tree was 0.111694 and 0.001862 tons, respectively of *Podocarpus falcatus* and *Rhus vulgaris* species and the average carbon per tree was 0.020469 ton.

Table 1. Trees and shrubs identified from Humbo forest.

Code	Scientific name	Family	Vernacular name /Wolayttattuwa/
1	<i>Acokanthera schimperi</i> (A.DC.) Schweinf.	Apocynaceae	Yiishinchaa
2	<i>Bersama abyssinica</i> Fresen	Melianthaceae	Walaseenuwaa
3	<i>Bridelia scleroneura</i> Muell.Arg	Euphorbiaceae	Kana-kasiliyaa
4	<i>Calpurnia aurea</i> (Ait.) Benth.	Fabaceae/Leguminosae	Maylluwaa
5	<i>Carissa edulis</i> Vahl	Apocynaceae	Laadiyaa
6	<i>Celtis Africana</i> Burm. f.	Ulmaceae	Isigalbbaa
7	<i>Combretum collinum</i> Fresen	Combretaceae	Ambbiyaa
8	<i>Croton macrostachyus</i> Hochst. ex A. Rich.	Euphorbiaceae	Ankkaa
9	<i>Dodonaea viscosa</i> (L.) Jacq.	Sapindaceae	Sankaaraa
10	<i>Eriobotrya japonica</i> F.	Rosaceae	Shiyyanttuwaa
11	<i>Faurea speciosa</i> Welw	Proteaceae	Diraa
12	<i>Ficus sur</i> Forssk	Moraceae	Loollaa
13	<i>Ficus vasta</i> Forssk.	Moraceae	Maaruwaa
14	<i>Flacourita indica</i> (Burm. f.) Merr.	Flacourtiaceae	Hagilaa
15	<i>Gareinia buchananii</i> Baker	Clusiaceae	Gili-gassaa
16	<i>Jacaranda mimosifolia</i> D. Don	Bignoniaceae	Jakkaranddaa
17	<i>Lannea schimperi</i> (Hochst. ex A. Rich).	Anacardiaceae	Mageeyyo
18	<i>Maesa lanceolata</i> Forssk	Myrsinaceae	Gergecuwa
19	<i>Manilkara butugi</i> Chiov	Sapotaceae	Saluwaa
20	<i>Milletia ferruginea</i> (Hochst.) Bak.	Fabaceae/Leguminosae	Zaagiyaa
21	<i>Myrsine africana</i> L.	Myrsinaceae	xanqqarsaa
22	<i>Mytenus arbutifolia</i> R.wilczek	Celastraceae	xuxuwaa
23	<i>Olea europea</i> (sub spec. <i>cuspidata</i>) L.	Oleaceae	Wogaraa
24	<i>Olinia rochetiana</i> A. Juss	Penaeaceae	Reecaa
25	<i>Ozoroa insignis</i> Del	Anacardiaceae	Dachchiyaa
26	<i>Pappea capensis</i> Eckl. & Zeyh.	Sapindaceae	Ceecciliyaa
27	<i>Podocarpus falcatus</i> (Thunb.) R.Br. ex Mirb	Podocarpaceae	Zigaa
28	<i>Prunus Africana</i> (Hook. f.) Kalm.	Rosaceae	Karetta -mittaa
29	<i>Psydrax schimperiana</i> (A. Rich.) Bridson	Rubiaceae	Gaayiyaa
30	<i>Rhus vulgaris</i> Meikle	Anacardiaceae	Mucakuwaa
31	<i>Samium ellipticum</i> (Krauss) Pax	Euphorbiaceae	Wusaanguwaa
32	<i>Schrebera alata</i> (Hochst.) Welw.	Oleaceae	Qaraa
33	<i>Senna spetemtrionalis</i> (Viv) Ihwin and Barnery	Fabaceae	Shuquwaa
34	<i>Spatodia nilotica</i> Seem	Bignoniaceae	Ciishsha-zaafiyaa
35	<i>Stereopermum kunthianum</i> Cham	Bignoniaceae	Saggaa
36	<i>Syzigium guineense</i> (L.) Skeels	Myrtaceae	Ochchaa
37	<i>Terminalia brownii</i> Fresen	Combretaceae	Sobbuwaa
38	<i>Terminalia laxiflora</i> Engl. and Diels	Combretaceae	Digissuwaa
39	<i>Vangueria apiculata</i> K.Schum	Asteraceae	Guluwaa
40	<i>Vangueria madagascariensis</i> Gmel.	Rubiaceae	Gonniwaasiyaa
41	<i>Vernonia myriantha</i> Hook.F.	Asteraceae	Buuzzuwaaa

4.2. Carbon Stock and Carbon Dioxide Sequestered In the Different Carbon Pools

About 13.62%, 6.4%, 5.55% and 74.43% of carbon was located in above ground biomass, below ground biomass, dead litter biomass and soil organic carbon, respectively. The percentage of carbon dioxide sequestered in respective carbon pools was the same, since it is converted by the same factor.

Table 2. The different carbon pools and carbon dioxide sequestered.

Rank	AGC	BGC	CL	SOC	Total
Max	107.927	50.7257	17.8524	185.127	361.63
Min	13.221	6.21389	7.047	32.0035	58.4855
Average	30.770	14.4629	12.547	168.202	225.983
Rank	AG(CO ₂)	BGCO ₂)	L(CO ₂)	S(CO ₂)	Total
Max	396.09	186.16335	65.5183	679.4	1327.172
Min	48.5212	22.805010	25.8625	117.45	214.6387
Average	112.928	53.076501	46.0493	617.3	829.3538

4.3. Altitudinal Variation of Carbon and Carbon Dioxide Sequestration

Due to the altitudinal gradient, the values of different carbon pools varied (Table 3). The lower altitudinal class had the highest carbon pool of 1171.17 ton/ha, where as the middle altitudinal class had the lowest carbon pools with the recorded value of 1008.27 ton/ha. The upper class had the value in between the two records and it was 1116.05 ton/ ha. Their respectively sequestered carbon dioxide was 13377.13, 3700.33 and 4095.91 ton/ha (Table 3). However, this variation is not significant. The result of one way ANOVA for Above and below ground carbon, Litter carbon and Soil carbon, are ($F=0.396$, $P=0.681$, $\alpha=0.05$), ($F=0.056$, $P=0.946$, $\alpha=0.05$) and ($F=1.118$, $P=0.359$, $\alpha=0.05$), respectively. Necessarily, the variation of carbon dioxide sequestered between altitudinal gradient was not significant, since the conversion factor used was the same.

Table 3. Altitudinal variations of carbon pools and their sequestration of carbon dioxide (CO₂).

Elevation class	Higher (1792-1842 m)	Middle (1741-1791 m)	Lower (1690-1740 m)
AGC	117.91	140.57	138.96
AG(CO ₂)	432.731	515.91	509.97
BGC	55.42	66.0702	65.30
BG(CO ₂)	203.38	242.48	239.68
CL	60.78	62.90	64.52
L(CO ₂)	223.08	230.86	236.79
SOC	881.94	738.71	902.38
S(CO ₂)	3236.71	2711.08	3311.76
C	1116.05	1008.27	1171.17
CO ₂	4095.91	3700.33	13377.13

5. Discussion

5.1. Carbon Stock in the Different Carbon Pools

Table 4. Results of studies conducted by other researchers in tropical areas.

Researcher(s)	AGC	BGC	CL	SOC
Outside Ethiopia				
Ullah and Amin, 2012	96.13	14.61	4.2	168.15
In Ethiopia				
Mesfin Sahile, 2011	23-517	1.3-103	0.78-13.94	26.64-175
Tulu Tolla, 2011	122.85	25.97	4.95	135.94
Adugna Feyissa et al 2013	19-782.28	8.06-332.89	0.33-7.53	51.30-148.78
Mohammed Gedefaw et al, 2014	306.37	61.52	0.90	274.32

The above ground carbon stock of Humbo forest was between 13.22 to 107.93 ton/ha with the average value of 30.77 ton/ha. When compared with other studies, it was less than the values of all studies listed above. In other words, it is 75%, 17%, 27%, 52% and 81% less than the carbon stock of Bangladesh forest (Ullah and Amin, 2012), Egdu forest (Adugna Feyissa et al 2013), Menagesha Suba state forest (Mesfin Sahile, 2011), selected church forest (Tulu Tolla, 2011) and Tara Gadam forest (Mohammed Gedefaw et al 2014), respectively. This is due to the reason that other studies were conducted in trees with larger DBH and height than that of Humbo forest. The DBH and height of trees and /shrubs in Humbo were small, because, it was secondary forest. In this study, secondary forest is to mean the forest restored after a long period destruction. The Below ground carbon stock of this study was 0.47 times above ground carbon and the result was in the range between 6 and 50.723 ton/ha with the average value of 14.46 ton/ha. This is 41%, 14.6% and 61% less than the below ground carbon of Bangladesh forest, Egdu forest and Tara Gadam forest, respectively. However, it was 64% and 4% greater than that of Menagesha Suba state forest and selected church forest, respectively.

Despite of other carbon pools of Humbo forest, the carbon pool of leaf litter was greater than the value obtained by all of the studies mentioned above. The estimated value of this study varied between 7.05 and 17.85 ton/ha, having the average value of 12.55 ton/ha. It is 25%, 91%, 26%, 41.5% and 86% greater than that of estimated value of Bangladesh forest, Egdu forest, Menagesha Suba state forest, selected church forest and Tara Gadam forest, respectively. This is because of the reason that the difference between sub-sample fresh weight and sub-sample oven-dry weight of the litter was small, since it was dry due to dry air condition (low moisture content). This resulted in large proportion of litter biomass, which maximized the total carbon in litter when multiplied by percent of carbon.

Olive *et al.*, (2006), stated that 51% of the total carbon stock of tropical deciduous forest of Mexico found in the soil when the bulk density of soil up to 20cm of depth was 0.9g/cm^3 . Normally, soils are the largest carbon pools in global terrestrial ecosystems, because they can contain three times more C than that contained in vegetation (Schlesinger, 1990), and about 32% of global soil C pool is in tropical soils (Lal, 2004). These all studies show that the soil organic carbon is greater than the above ground carbon (carbon in vegetation). Similarly, the carbon present in the soil of Humbo forest ranges from 32 to 185.13 ton/ha, with the average value of 168.2 ton/ha (when the average bulk density was 0.55g/cm^3), was larger than that present in the plants. It was 23%, 9% and 11% greater than the estimated average value of Egdu forest, Menagesha Suba state forest and selected church forest, respectively. However, it was 23% less than the estimated value of Tara Gadam forest.

By and large, the total carbon stock of the Humbo forest resulted in the maximum and minimum carbon pool of 361.63 and 58.49 ton/ha, respectively, with the average value of 225.98 ton/ha. Similarly, the maximum and minimum CO_2 sequestered by the Humbo forest was 1327.17 and 214.64 ton ha^{-1} respectively, with the average value of 829.35 ton ha^{-1} .

5.2. Altitudinal Variation of Carbon Stock and Carbon Dioxide Sequestration

Moser *et al* (2011) showed that the Leaf biomass, stem wood mass and total aboveground biomass (AGB) decreased by 50 to 70% between 1050 and 3060 m.

According to Sheikh *et al* (2009), the stocks of SOC were found to be decreasing with increasing altitude: from 185.6 to 160.8 t C/ha and from 141.6 to 124.8 t C/ha in temperate (*Quercus leucotrichophora*) and subtropical (*Pinus roxburghii*) forests, respectively. Both of these studies showed that the carbon pools decrease with increasing altitude. Similarly, in this study the carbon in litter decreased by 2% between 1690 and 1842 meters.

The AGC, BGC and SOC value of this study varied with altitudinal range, but there was no direct increment or decrement. The one way ANOVA states that the change is not significant. In the case of SOC, the variation was due to the reason that the soil type throughout the study area was similar (clay soil), and also the species composition was similar even though the frequency varied. Likewise, the above and below ground carbon varied with altitude gradient due to the size of trees (DBH and/or Height) of a given species varies with area. And also, it was because of tree felling in some area and others not, some areas were fenced and controlled while others were not. Generally, this study showed that there was no significant variation of both carbon pools and Carbon dioxide sequestered between altitude gradient.

5.3. Financing Humbo Forest (Implication for Climate Change Mitigation)

The average wholesale price for buyers of carbon offsets on the voluntary offset market is about \$7.34/t CO_2e (RPN, 2009).

By applying the value on the average carbon dioxide equivalent, the result was \$6087.429. The value varies between \$1575.5 and \$9741.43USD. This information helps the community members to be interested to manage their forest by themselves by understanding that they will be paid for keeping their forest. This implies that the forest managed for carbon trading (to get money) indirectly sequesters about 829.35 ton/ha, in average.

6. Conclusion

Over all, Humbo forest is one of the forests in tropical dry areas with the annual average rainfall of 850mm, which is very suitable for *Syzigium guineense* (L.) Skeels and it is very difficult for the growth and development of *Prunus africana* (Hook. f.) Kal. It had a total of 41 species having 7,389 individuals, belonging to 38 genera and 25 families. The total carbon stock and carbon dioxide sequestered was 225.98 ton ha^{-1} and 829.35 ton ha^{-1} , respectively. There was no significant variation of carbon pools between altitudinal ranges. The total capital estimated for hectare of this forest was \$6087.429USD in average and the value varies between \$1575.5 and \$9741.43 USD. This plays a great role in the mitigation potential for climate change in combination to forests managed by World vision in the opposite side of the study site in Humbo.

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