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Area Closures: A Climate Smart Approach to Rehabilitate Degraded Lands and to Improve Livelihoods

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Abstract
Ethiopia has been implementing Productive Safety Net Program (PSNP) and Household Asset Building Program (HABP) that are important as complementary food security programs that involve establishment of area closures to rehabilitate degraded lands. Forest inventory using systematic random sampling was conducted in 9 PSNP area closures and one agroforestry system located in six National Regional States of Ethiopia to provide up-to-date and reliable information/data on existing growing stock, woody biomass resources and the actual quantities of carbon stored. The above ground biomass and carbon stock and carbon sequestration potential of PSNP area closures were estimated using existing allometric equations and conversion factors, respectively. The above ground biomass at the PSNP area closures ranged between 2.09±0.83tone/ ha and 22.21±1.86 ton/ ha. The aboveground biomass of woodlots, Enset and Coffee based agroforestry system and scattered trees on farm at Damote Gale agroforestry system was 33.27±3.33, 12.92 and 1.93±0.57 tone/ha, respectively. The above ground carbon stock and carbon sequestration potential of PSNP area closures ranged from 1.045 to 11.105 tones/ha and from 3.83 to 40.72 tones/ha, respectively. The difference in the amount of above ground biomass, carbon stock and carbon sequestration potential might be attributed to the difference in site characteristics, climatic conditions and age of area closures. The present inventory work showed that rehabilitation efforts brought positive response in most of the PSNP area closures and most area closures qualify for carbon projects. The output also presented the current stock to measure the difference in carbon stock over years.
Keywords: Area closures, aboveground biomass, carbon fund, food security

1. Introduction

Forests are source and sink of carbon.Forests form a major component of the carbon reserves in the world's ecosystems (Houghton 2007) and greatly influence both the lives of other organisms and human societies (Whittaker & Likens 1975). An increase in forest stock per unit area increases stored carbon while the decrease in forest stocks decreases stored carbon. Carbon sequestration potential of forests has attracted much attention in mitigating climate change.The increase in forest resources through protecting the existing forests and bringing back the degraded forest lands is a recommended strategy for mitigating climate change (Pacala & Socolow 2004).

Vegetation resources of Ethiopia are classified in to 12 vegetation types (Friis et al. 2010). These vegetation resources provide various benefits in the form of wood, food, income, and watershed protection that play critical role in enabling people to secure a stable life and/or welfare. However, these vegetation resources are declining as a result of deforestation and degradation. The main deriving forces include natural, anthropogenic and policy-related factors such as unsustainable exploitation of forest products, overgrazing, and clearance of forest land for crop cultivation, poverty, unexpected diseases and pest prevalence (Edinam 2005; Berhane et al. 2006).

Sustainable management together with wise utilization and conservation of the remaining vegetation resources and rehabilitation of degraded forest resources would provide economic, social and ecological benefits. This requires designing economically feasible, socially acceptable and ecologically viable management and conservation strategies of the resource. In this regard, Ethiopia has initiated a number of projects including soil and water conservation works and the establishment of area closures through bilateral and/or multilateral financial assistance. As a result, communities have started establishing area closures, a promising practice, in different parts of the country with the aim of fighting against land degradation and promoting their re-vegetation endeavors to prevent further degradation (Berhane *et al*. 2003).

Area closure denotes an area set aside with the exclusion of agricultural practices (cultivation and grazing) to assistregeneration of natural vegetation (Shitarek *et al*. 2001). Area closure is a type of land management practices implemented to rehabilitate degraded land with a clear biophysical impact on formerly degraded areas. Nyberg *et al*. (2014) also explains that area closures recover both above ground carbon and soil carbon through recovering vegetation cover. They enhance growth of grass and woody vegetation and improve the microclimate of an area. And it is one of the climate adaptation mechanisms, which help in rehabilitating a specified area. Moreover, it is one of the interventions that boosts land productivity and plays a key role in carbon sequestration, thus, helps in mitigation of climate change. Carbon sequestration in area closures is vital for greenhouse gas removals and is a means of carbon finance according to a set agreement in Kyoto protocol

(IPCC 2007). Study conducted by Wolde (2013) in north Ethiopian highlands reveals that area closures are a viable option to restores ecosystem carbon sequestration and working on them is important to establish baseline data for carbon financing projects to benefit from carbon finance premium and encourage farmers/pastoralist to participate in land management practices. Thus, quantifying and documenting carbon stock in selected area closures in Ethiopia using scientifically proved IPCC procedures made us utilize climate funding opportunities.

Ethiopia has vast land which is close to 36 million hectares for CDM area closures projects. It was therefore convincing that the Ethiopia has potential prospects for generating carbon finance in the forestry sector (Forum Brief 2011). Thus, Productive Safety Net Programme (PSNP) has been implemented in climate change mitigation (through sequestered carbon), climate change adaptation (through environmental rehabilitation of degraded hillsides) and climate change resilience (though expanding the range of household assets) in the last decades in various regions of the country. By enhancing effectiveness of PSNP, climate change resilience adaptive capacity of communities and households can be improved together with climate change mitigation options. Carbon pools of PSNP area closures is a valuable resource of greenhouse gas removals which would not be available if these areas were to become cultivated or get rid of tree/shrub vegetation. This opens up the potential for climate funding opportunities for the PSNP.

Despite the PSNP supported plantations/ afforested or reforested areas in Ethiopia are believed to contain important carbon stocks, there is limited up-to-date and reliable information/data on existing growing stock, woody biomass resources and the actual quantities of carbon stored. Moreover, qualifying for funding under the Clean Development Mechanism (CDM) and the World Bank Carbon Fund requires obtaining the rigorous data standards required for qualification.

Climate Smart Initiative (CSI) is an initiative to strengthen Productive Safety Net (PSNP) and Household Asset Building Program (HABP) by systematically integrating the implications of climate change now and determining how these programs will evolve after the two programs phased out. The second phase of CSI had piloted clusters of bundled climate smart activities, analyzed lessons-learned, and developed a road map for the transformation of PSNP into an instrument that helps people adapt to and manage climate risks. One of the program activities of Climate Smart Initiative (CSI)was to help identify and leverage climate funding opportunities through commissioning a national survey of soil and above ground biomass carbon levels in PSNP closures stratifying the country by major agro-ecological zone, major soil type and number of years of closure. Thus, collating and providing comprehensive information on woody biomass resource inventory was one of the highest priorities of CSI-II. With this rationale, forest inventory has been conducted in 10 PSNP weredas located in six National Regional States of Ethiopia. We characterized the stand structure and determined the aboveground biomass, carbon stock and carbon sequestration potential of PSNP area closures and agroforestry system. The results were evaluated in the light of changing area closures elsewhere, and the potential of area closures to qualify for carbon projects was also discussed.

2. Materials and Methods

2.1 Description of study sites

The study was conducted at 10 weredaswhere PSNP and HABP has been implemented to increase household, community and national resilience to climate shocks and stress; and to commit to a green, low carbon development path. One of the activities implemented by both programmes was establishing area closures. Both Programs were assisted by CSI II program that was designed to strengthen the communities/householdsto become climate smart through systematically integrating the implications of climate change. The CSI II program targeted 24 woredas located in 6 national regions: Afar, Amhara, Oromiya, SNNPR, Somali, and Tigray. The present study has been conducted in nine PSNP area closures and one agroforestry landscape (Table 1) that are stratified by major agro-ecological zone and livelihood zones.

Table 1: Agro-ecology and livelihood zone of study areas

Region	Woreda	Agro-ecology zone	Livelihood zone
Amhara	Kobo		Dega Zone: Wheat, barley, oxen, sheep (LZ 1)
Amhara	Habru	Dry weinadega	
Afar	Chifera	Dry kolla	Pastoral (LZ 8)
Oromiya	DaroLebu	Dry weinadega	Non-Vertisols: WoinaDega – Wet/moist Zone: Maize, wheat, cattle, small stock (LZ 3),
Oromiya	Dolo Mena	Dry kolla	LZ 7
SNNPR	Halaba	Dry weinadega	Mixed Crop-Livestock production systems on Non-Vertisols: WoinaDega – Wet/moist Zone: Maize, wheat, cattle, small stock (LZ 3)
SNNPR	Damot Gale	moist weinadega	
SNNPR	DembaGofa	moist weinadega	Enset is co-dominant with cereals with livestock (LZ 5) and
Somalia	Harshin	Dry kolla	Agro-Pastoral (LZ 7),
Tigray	Gulomehada	Dry weinadega	Dega Zone: Wheat, barley, oxen, sheep (LZ 1),

2.2 Vegetation survey

The development of the baseline information on carbon stock and carbon sequestration potential of PSNP-PW closured areas is a key step to ensure accurate crediting of performance of closure areas for their carbon budget (OECD/IEA 2003) as GHG benefits of a project activity are computed as the difference in carbon stocks and other GHG emissions of the project activity and the baseline.

To quantify the carbon stock in PSNP area closures reliable estimates of the above ground biomass are required. To measure the aboveground biomass in PSNP area closures, an indirect method, allometric equations were employed. This method bases output of inventory work with easily accessible and measurable woody plant parameters such as diameter and height which can be measured non-destructively (Aboal *et al*. 2005; Whittaker & Woodwell 1968).

Systematic random sampling was employed with sample plots size of 20m X 20m (0.04 ha) being laid out along parallel transect lines in each of PSNP area closure for vegetation survey. (The transect lines were laid systematically to cover the different strata that differ in altitude and slope within the closure area). All tree/shrub species with ≥ 2 cm diameter at stump height (DSH, at 30 cm) were identified and measured for their diameter at stump height (DSH) using caliper. The survey was conducted during the dry season, thus, no data was collected for herbaceous plants. This can be considered as a limitation for this study.

The carbon stock of agroforestry niche (e.g. Damote gale, Southern Nations Nationalities Peoples Region (SNNPR), was assessed following Negash *et al*. (2013) methodology. First we categorized the observed agroforestry systems into three agroforestry practices:

I. Enset-coffee based agroforestry systemthat involves enset, coffee and tree and shrub species
II. Scattered trees on farm where farmers grow crop while maintaining scattered trees on their farm
III. Woodlots where individual farmers allocate some land to grow trees in the form of woodlot.

Enset-coffee based agroforestry system was inventoried by randomly selecting 10 farms that belongs to 10 households. In each of the 10 selected farms, two 10 x 10 m plots that fairly represent the farm in terms of density as well as age of individual Ensetin the farm were established. To estimate aboveground biomass of Enset, all individuals of Ensetwith 3 - 5 years of age were identified and measured at a height of 10 cm above the ground (basal diameter, d10), with a diameter tape and total height (H) with Sunto clinometer following Negash *et al*. (2013). Total height refers to the distance from the ground to the petiole of the last leaf to emerge. To estimate aboveground biomass of coffee in the same plot, all coffee plant stems having breast height diameter of ≥ 2.5 cm and height >1.5 m were recorded and measured for their stump diameter at 40 cm height above the ground, breast height diameter at 1.3 m, and total height following Negash *et al*. (2013). Total height refers to the distance from the ground to the petiole of the last leaf to emerge. Methods used in PSNP area closure were employed to estimate aboveground biomass of trees and shrubs in Enset-coffee based agroforestry system.

To quantify the aboveground biomass of trees and shrubs in the second agroforestry system called scattered trees on farms, 10 households were randomly selected. In each household, one plot that measure 25 m X 25 m were laid out and all trees within the plot that measure ≥ 2 cm DSH were identified and measured for their DSH.To quantify the aboveground biomass of trees and shrubs in woodlots, 10 households with woodlots were randomly selected. 10 m X 10 m plots were laid out in each woodlot and all trees and shrubs with ≥ 2 cm DSH in the plots were identified and measured for their DSH.

2.3 Above ground biomass Estimation

Biomass is defined as mass of live or dead organic matter.Changes in time of vegetation biomass per unit area can be used as an essential climate variable, because they are a direct measure of sequestration or release of carbon between terrestrial ecosystems and the atmosphere (Condit 2008).The allometricequation developed by woody biomass inventory (WBISPP 2004) have been employed to estimate the above ground biomasses of trees and shrubs in PSNP area closures and scattered trees on farm in Damet Gale. In Coffee - Enset based agroforestry system allometric equations developed by Negash *et al*. (2013)were employed (Table 2). Unit of measure for aboveground biomass in our study was tone/ha. Among non-destructive biomass estimation techniques, allometric equations usually give the most rigorous estimates as long as the equations are derived from enough number of representative trees in considered agroecology (Condit 2008; WBISPP 2004).

2.4 Estimation of carbon stock and carbon sequestration potential

The carbon stock in above ground biomass was calculated by multiplying biomass by conversion factor. For the conversion of tree biomass to carbon stocks we considered a common proxy based on the assumption that 50% of the biomass is carbon (Malhi *et al*. 2004; Roy *et al*. 2001). The carbon stock of area closures was then half of the above ground biomass as indicated below:

C=ABGX 0.5

C = carbon stock density [Tone C/ ha],

ABG = the aboveground biomass of the tree/shrubs [Tone/ ha],

To determine the carbon sequestration potential of the area closures the total carbon stock was converted to tons of CO_2 equivalent by multiplying it by 44/12, or 3.67 (Pearson *et al*. 2007).

3. Data Analysis

The stand structure of area closures is explained in terms of density and population structure. Density of trees/shrubs/enset/coffee is calculated based on the total number of individuals recorded in all plots. To determine the population structure of the whole tree/shrub community at studied sites first all individuals encountered in the plots were grouped into 7 arbitrarydiameter at stump height (DSH) classes: 1 = 0-5 cm, 2 = 5-10 cm, 3 = 10-15 cm, 4 = 15-20 cm, 5 = 20-25, 6 = 25-30 and 7 = >30 cm (Peters 1996). Then, by employing the total numbers of individuals that were grouped in the different arbitrary DSH classes, the population structure of the whole tree/shrub community was constructed using histograms of DSH class distributions.

Table 2. List of allometric equations employed for estimating aboveground biomass of PSNP area closures.

No.	Region	Wereda	Agroecology zone	Allometric equation	Reference
1	Oromiya	Delomena	Dry kolla	Y = (0.4861 x DSH) + (0.1659 x (DSH*(EXP2.2)))	WBISPP, 2004
	Oromiya	Darolebu	Dry weinadega	Y = (0.3197x DSH) + (0.0383x(DSH exp 2.6))	WBISPP, 2004
2	Amhara	Kobo	Dry Kolla	Y = ((0.04861*DSH)+(0.1659*DSH*(EXP(2.2)))	WBISPP, 2004
	Amhara	Habru	Dry weinadega	Y = (0.3197*DSH)+0.0383*(DSH*EXP(2.6))	WBISPP, 2004
3	SNNPR	Halaba	Dry weinadega	Y = (0.3197x DSH) + (0.0383x(DSH exp 2.6))	WBISPP, 2004
	SNNPR	DembaGofa	moist weinadega	Y = (0.3658*DSH)+(0.1144*DSH*(EXP(2.2)))	
	SNNPR	Damot Gale (Homestead)			
		Enset	moist weinadega	LN (Y) =-6.657 +2.316*(LN(DSH))+0.124*(LN(H))	MeseleNegash et al 2013
		Coffee	moist weinadega	$y= 0.147*d^2_{40}$	MeseleNegash et al 2013
		Trees/shrubs in Coffee	moist weinadega	Y = (0.3658*DSH)+(0.1144*DSH*(EXP(2.2)))	WBISPP, 2004
		Scattered trees on farm	moist weinadega	Y = (0.3658*DSH)+(0.1144*(DSH*EXP(2.2)))	WBISPP, 2004
		Woodlots		Y= (0.3658*DSH)+(0.1144*(DSH*EXP(2.2)))	WBISPP, 2004
4	Tigray	Gulomehada	Dry weinadega	Y= (0.3197*DSH)+(0.0383*(DSH*EXP(2.6)))	WBISPP, 2004
5	Somalia	Harsin	Dry kolla	Y = (0.4861*DSH)+(0.1659*(DSH*EXP(2.2)))	WBISPP, 2004
6	Afar	Chifera	Dry kolla	Y = (0.4861*DSH)+(0.1659*(DSH*EXP(2.2)))	WBISPP, 2004

4. Results and Discussion

4.1 Stand characteristics and standstructure of PSNP area closures

The number of observed tree/shrub species in PSNP area closures ranged from 6 to 58. Highest number of species is observed at Demba Gofa, SNNPRs (58 species) followed by Delomena, Oromiya (54) while the lowest number of species is observed at Harsin, Somalia (6) and Chifera, Afar (6). The density of naturally regenerating trees/shrubs (trees/shrubs ≥ 2 cm DSH) in the studied sites varied considerably. Highest density was recorded at DembaGofa (SNNPR) (3224 individuals/ ha) while lowest density was recorded at Harsin (Somalia Region) (100 trees/ha). Six tree species were encountered in woodlots established within PSNP area closures at

Delomena, Oromiya with 4117 trees/ha. Thirteen species were encountered in woodlots at DamoteGale agroforestry system with 1860 trees/ha. Eleven tree species with 78 trees/ha were observed on farm lands of DamoteGale agroforestry system. 17900 and 685 individual Ensetand coffee plants were found at homestead agroforestry system of Damote gale, respectively (Table 2). The densities of trees/shrubs/coffee/enset are indicated in Table 3.

The impact of the two programs in rehabilitating the degraded lands through establishing area closures expressed in terms of vegetation composition, diversity, and density varies with the biophysical conditions and the socio-economic and mode of life (Mekuria *et al*. 2011). According to the perception of the local people the vegetation resources of some PSNP area closures were very limited or nearly absent before the intervention and after the intervention the area closures are recovering well in eight study sites which is indicated in terms of increase in number of species and density of trees after the intervention. Although no quantitative data was collected, the local people expressed that the area closures had increased grass cover, decreased soil erosion, and increased rainfall frequency following the regeneration of vegetation on the degraded lands. Such improvements are expected as nature can bring up the vegetation systems through secondary succession as far as the human related disturbances are abandoned (Silver *et al*. 2000).

Most area closures reported to have similar recovery in Ethiopia in terms of vegetation composition, diversity, and density (Berhane *et al*. 2007; Mengistu *et al*. 2005; Yami *et al*. 2006). The lower impact of area closures in rehabilitating degraded areas of Harsin in Somalia and Chifera in Afar might be due to the higher aridity and pastoral mode of life that limit the practicality of complete exclusion of livestock in the area closures.

Table 3.Number of tree/shrub species recorded and density of all trees at PSNP area closures

No.	Region	Wereda	Livelihood zone	No. species observed	Density (No. trees/ha
1	Oromia	Delomena	7	54	746
2	Ormiya	DaroLebu			
		Natural forest	3	20	838
		Woodlot	3	6	4117
3	Amhara	Kobo	1	25	530
4	Amhara	Habru	4	29	2709
5	SNNPR	Halaba	3	37	1246
6	SNNPR	DembaGofa	5	58	3224
7	SNNPR	Damot Gale (Homestead)	6		
		Enset		1	17900
		Coffee		1	685
		Trees/shrubs		4	85
		Scattered trees on farm		11	78.4
		Woodlots		13	1860
8	Tigray	Gulomehada	1	19	488
9	Somalia	Harsin	4	6	100
10	Afar	Chifera	8	6	234

The community structure of almost all PSNP area closures showed an inverse J shape structure that displays a greater number of small trees/shrubs, and an almost constant reduction in numbers from one size-class to the next.The young individuals belonging to 0 – 5 and 5-10 cm DSH class dominated almost in naturally regenerating forest of PSNP area closures . This type of structure is characteristic of vegetation with good rejuvenation and indicates that PSNP area closures are rehabilitating well (Peters 1996, Richards 1952).There are almost no larger trees/shrubs indicating the heavy exploitation of forest resources in the past. The presence of many smaller individuals and few larger individuals is a very common phenomena in most studied area closures in Ethiopia (Birhane *et al*. 2007; Mekuria 2007). Community structure of trees/shrubs on agroforestry landscape and on enset-coffee based agroforestry system revealed irregular structure. On the agroforestry landscape more individuals were observed in the 2nd, 3rd and 7th DSH class whereas in Homesetad at Damote gale very few individuals in the first two DSH classes but relatively higher individuals in the higher DSH classes (Fig 1). Such type of structure is common in agroforestry landscapes that grow trees with multiple use (Gouwakinnou, *et al*. 2009).

4.2 Above ground biomass, carbon stock and carbon sequestration potential estimates of PSNP area closures and agroforestry system

The above ground biomass at the PSNP area closures ranged between 2.09±0.83tone/ ha and 22.21±1.86 ton/ ha. The highest above ground plant biomass was recorded at Demba Gofa, SNNPRS (22.21±1.86 ton/ ha), followed by Delomena, Oromiya (14.9 ± 1.08 tone/ha); and the lowest above ground aboveground biomass was recorded at Harsin, Somalia (2.09±0.83tone/ ha). Higher aboveground biomass was recorded in Woodlots of Darolebu area closure (39.18±11.84 tone/ha) followed by woodlots at Damote gale agroforestry system (33.27±3.33 tone/ha). The Enset and Coffee based agroforestry system at Damote gale attained aboveground biomass of 12.92 tones/ha. The observed above ground biomass in studied enclosures is within the range of Mekuria *et al*. (2011) reports for enclosures in Tigray Regional State. The total amount of aboveground biomass in PSNP area closures ranged from 21 to 8884 tones at Demba Gofa, SNNPRS. The total carbon stock ranged from 10.5 to 4442 tones. The total tCO2e ranged from 323.675 to 16287.33333 (Table 3). The difference in the amount of above ground biomass, carbon stock and carbon sequestration potential among PSNP area closures might be attributed to the difference in site characteristics, climatic conditions and age of area closures (Mekuria *et al*. 2011). Mekuria *et al*. (2011) had reported that soil clay content, precipitation, woody biomass, vegetation canopy cover, exclosure age, bulk density, stone cover, and slope had a strong correlation with aboveground above biomass and carbon stock. To qualify for a carbon project like REDD project, project size area or size of enclosures needs to be 30 – 40,000 ha. Based on this criteria, we can suggest that 8 out of the 10 studied enclosures (except enclosures in Afar and Somalia Regional state) could qualify for the REDD Project (Terra Global Capital 2009).

Table 4. Estimates of aboveground biomass, carbon stock and CO_2 equivalent for PSNP area closures

No.	Region	Wereda	Livelihood zone	Biomass (mean ton/ha ± SE,)	Carbon (ton/ha)	CO_2 equivalent (ton/ha) (44/12*C)
1	Oromia	Delomena	7	14.9 ± 1.08	7.45	27.32
2	Ormiya	DaroLebu				
		Natural forest	3	3.94 ± 1.3	1.97	7.22
		Woodlots		39.18±11.84	19.59	71.83
3	Amhara	Kobo	1	3.58±0.46	1.79	6.56
4	Amhara	Habru	4	9.50±0.59	4.75	17.42
5	SNNPR	Halaba	3	6.75±0.45	3.375	12.38
6	SNNPR	DembaGofa	5	22.21±1.86	11.105	40.72
7	SNNPR	Damot Gale (Homestead)	6			
		Enset		5.56±0.43	2.78	10.19
		Coffee		4.55±0.7	2.275	8.34
		Trees/shrubs		2.81±0.89	1.405	5.15
		Scattered trees on farm		1.93±0.57	0.965	3.54
		Woodlots		33.27±3.33	16.635	61.00
8	Tigray	Gulomehada	1	3.21±0.57	1.605	5.89
9	Somalia	Harsin	4	2.09±0.83	1.045	3.83
10	Afar	Chifera	8	3.9±1.05	1.95	7.15

5. Conclusion

Climate Smart Initiative (CSI) II efforts to strengthen and enhance the climate mitigation and adaptation potential of 24 weredas located in six Regional States showed a very positive result explained in terms of rehabilitating degraded lands. Almost all PSNP area closures are dominated by young individuals indicating regenerating stands. However, the two sites in Afar and Somalia Regional states are not as good as that of the other area closures. The difference might be due to the difference in terms of site conditions and climatic conditions which is harsh in Afar and Somalia and main livelihood or pastoral mode of life observed in the two regions. As rehabilitation efforts are showing positive response, it is advisable to develop baseline information on aboveground biomass and carbon stock of PSNP area closures. This report would thus represent key information on the current aboveground biomass and carbon stock of area closures to measure the difference in carbon stock over years. Seven out of the ten studied enclosures are expected to qualify for carbon projects like REDD as the size of area closures is greater than 30 ha. Further efforts that enhance carbon sequestration potential of the closed areas would open up the potential for climate funding opportunities for the PSNP closed areas.

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Figure 1: DSH class distributions of all tree/shrub individuals recorded at PSNP area closures (DSH class: 1= 0-5; 2= 5-10; 3= 10-15; 4= 15-20; 5= 20-25; 6= 25-30; 7 > 30 cm)