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Estimation of Carbon Sequestration Potential of Arid Land Afforestation Using Satellite Image Analysis and Ground Truth

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Abstract: As a countermeasure to the greenhouse effect, afforestation in arid areas has been proposed and tested in an arid area of Western Australia. According to the CDM/JI guidelines set by UNFCCC, the sequestered carbon amount accountable as carbon credit was estimated in this study. First, the sequestered carbon amount by planted trees was measured by repeated tree censuses. Second, the land use type (vegetation type) was estimated using LANDSAT images by statistical methods. Third, by repeated tree censuses, the Mean Annual Increment (MAI) at natural vegetation monitoring sites of each vegetation type was estimated, and this MAI data were used as the baseline of each type of vegetation. Fourth, the present biomass distribution was estimated using the SAVI index calculated from LANDSAT image, since the original vegetation must be clear-cut before afforestation sites were established. At last, the sequestered carbon amount accountable as carbon credit was estimated inside 45×50 km area, and this result revealed that carbon mitigation amount by this arid land afforestation was equivalent to 0.88% of Japanese CO_2 emission in 2008.

Key Words: *Acacia aneura*, CDM/JI, *Eucalyptus camaldulensis*, LANDSAT, Western Australia.

1. Introduction

As countermeasures against the greenhouse effect, two types of strategies can be used. One is emission reduction, and the other is Greenhouse Gas (GHG) capture. Typical examples of emission reduction are improving energy-saving technology and renewable energy development, and those of GHG capture are Carbon Capture and Storage (CCS) and afforestation. Afforestation and forest management were considered as effective countermeasures against global warming, thus many attempts were tested in the literatures (Moor *et al*., 2001; Grünzweig *et al*., 2003; Yamada *et a*l., 2003; Ravindranath *et al*., 2006; Roxburgh *et al*., 2006).

To evaluate the amout of effective carbon sequestered from atmosphere by afforestation or reforestation activity, Clean Development Mechanism / Joint Implementation (CDM/JI) framework was decided by United Nations Framework Convention on Climate Change (UNFCCC, 2006). According to UNFCCC (2006), accountable carbon amount (carbon credit) by afforestation, which is effective for carbon mitigation, was roughly described as follows. The accountable carbon amount should be calculated as the “actual net GHG removals by sinks” minus the “baseline net GHG removals by sinks” minus “leakage” in five carbon pools (above-ground biomass, below-ground biomass, litter, dead wood and soil organic carbon). Of these five carbon pools, the above-ground biomass and below-ground biomass will change rapidly after afforestation.

In this study, as a first step, accountable carbon amount in two types of carbon pools (above-ground biomass and below-ground biomass) by arid land afforestation was estimated using satellite image analysis and ground truth. The afforestation test site was established in 1999 and has been monitored at regular intervals (Yamada *et al*., 2003).

2. Materials and Methods

2.1. Research area

The research area of this study is Sturt Meadows (28°40'S, 120°58'E) near Leonora, located about 600 km from Perth, the provincial capital of Western Australia. The range of our research area is approximately 45 km from east to west and 50 km from north to south. This research area belongs to the Murchison region of Interim Biogeographic Regionalization of Australia (IBRA) Version 5.1 (Environment Australia, 2000). The mean annual rainfall is about 200 mm in this area, thus categorized as an arid area (Yasuda *et al*., 2001). The Murchison environment was described as having Mulga (*Acacia aneura*) low woodlands, often rich in ephemerals, on outcrop hardpan wash plains and fine-textured quaternary alluvial and eluvial surfaces mantling granitic and greenstone strata (Environment Australia, 2000). From the vegetation classification results (Suganuma *et al*., 2010), this research area

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consisted of 5 types of vegetation, i.e., *Acacia* forest and woodland, *Eucalyptus* forest and woodland, bare ground, halophyte, and hydrosol (salt lake).

Afforestation test site named site C, which is the largest site, consists of 12 sub-plots, and each sub-plot adopted hardpan-blasting afforestation method (Yamada *et al*., 2003; Kojima and Egashira, 2011) and water-harvesting method. Many kinds of trees were planted in each sub-plot with 7 × 7 m spacing, and planted tree species were *Acacia aneura*, *A. tetragonophylla*, *Casuarina obesa*, *Eucalyptus camaldulensis*, *E. salubris*, *E. torquata*, *E. lesouefii* and *E. striclandii*. The dominant tree species was *E. camaldulensis*.

2.2. Estimation of accountable carbon amount

According to the assessment method by UNFCCC (2006), the accountable carbon amount resulted from afforestation in this research area was calculated using following equation.

$$AC = [\{(MAI_A - MAI_B) \times N - B\} \times 0.5 \times (44/12) - E] \times Area \quad (1)$$

Where AC is accountable carbon amount (Mg-CO_2); MAI_A is Mean Annual Increment (MAI) in afforestation sites (Mg ha^{-1} $year^{-1}$); MAI_B is MAI in natural vegetation (Mg ha^{-1} $year^{-1}$); N is afforestation duration (year); B is biomass loss amount by clear-cut of natural vegetation (Mg ha^{-1}); 0.5 is carbon conversion factor from biomass; 44/12 is CO_2 conversion factor from carbon; Area is afforestation applicable area (ha); E is CO_2 emission of afforestaion site creation (Mg-CO_2 ha^{-1}).

MAI_A was estimated from repeated tree census from June 2000 to August 2009 using allometric equations reported by Suganuma *et al*. (2006). Among tree species planted inside Site C, some trees grew poor or dead but some trees grew well, thus MAI_A should become low value, thus we calculated another MAI_A value assuming that this afforestation site consisted of single species which has the highest growth rate with the highest survival ratio.

MAI_B in each vegetation was estimated from tree census data from 1997 to 2007 using allometric equations reported by Suganuma *et al*. (2006). Vegetation (*Acacia* woodland, bare ground and vegetation transition area) was classified by Suganuma *et al*. (2010).

N was set as 30 years which was determined as long term afforestation period by UNFCCC (2006). In addition, 30 years was also set from maximum biomass data of *Eucalyptus* forest in this research area (150 Mg ha^{-1}) and from MAI data of *Eucalyptus camaldulensis* trees (5 Mg ha^{-1} y^{-1}).

B was estimated using satellite image of LANDSAT TM with vegetation index. Detailed method was described in Suganuma *et al*. (2010).

E was estimated from Life Cycle Assessment (LCA) as shown in Tahara *et al*. (2009) and Kojima and Egashira (2011). Total energy amount of producing materials and total consumed liquid fuel by afforestation site creation was accounted, and then E was estimated as 7.16 Mg-CO_2 ha^{-1}.

Area, represents afforestation applicable area, was estimated using equation (1) and satellite image data. Afforestation applicable area was calculated from selected locations where sequestered carbon amount by afforestation overcame baseline data plus emitted carbon amount by site creation and clear-cut biomass of original vegetation. However, since afforestation site named site C adopted water-harvesting technology, the actual afforestation area was 1/4 of calculated area.

Using equation (1), the estimated accountable carbon amount inside this research area was compared with the total emitted carbon amount inside Japan in 2008 (Ministry of Environment of Japan, press release).

In addition, leakage was estimated as 0 in this research because the main land use type was extensive grazing and only 25% of area was used for afforestation. Furthermore, as afforestation activities will continue with a phased approach, original grazing activities remain undisturbed. Therefore, leakage of this arid land afforestation was assumed as 0.

3. Results and Discussion

Carbon sequestration rate of site C was 2.96 Mg-CO_2 ha^{-1} $year^{-1}$ (*S.E.*: 0.30). Tree species with the fastest growth rate with the highest survival ratio was *Eucalyptus camaldulensis*, and its carbon sequestration rate was 8.51 Mg-CO_2 ha^{-1} $year^{-1}$. Estimated carbon sequestration rate of natural vegetation (baseline) was 0.19 Mg-CO_2 ha^{-1} $year^{-1}$ in bareground, 1.95 Mg-CO_2 ha^{-1} $year^{-1}$ in vegetation transition area and 0.20 Mg-CO_2 ha^{-1} y^{-1} in *Acacia* woodland. Carbon emission of afforestation site creation was estimated by LCA as 7.16 Mg-CO_2 ha^{-1} (Tahara *et al*., 2009; Kojima and Egashira, 2011).

By introducing above estimated values into equation (1) except afforestation applicable area, sequestered CO_2 amount and its allocation (Total sequestered carbon amount, accountable carbon amount, baseline, carbon loss amount by clear-cut of natural vegetation, carbon emission amount by afforestation site creation) is shown on **Figure 1**. The X axis of Figure 1 shows the biomass amount in natural vegetation before afforestation (Mg ha^{-1}), and the Y axis of Figure 1 shows the total amount of sequestered carbon amount inside afforestation area in 30 years and its allocation (Mg-CO_2 ha^{-1}). Figure 1 shows the results when afforestation sites are to be created in bare ground, vegetation transition area and *Acacia* woodland. From these results, accountable carbon amount in vegetation transition area which had high baseline data was quite low, i.e. carbon sequestration efficiency was poor. On the other hand, the efficiency was good in bare ground and

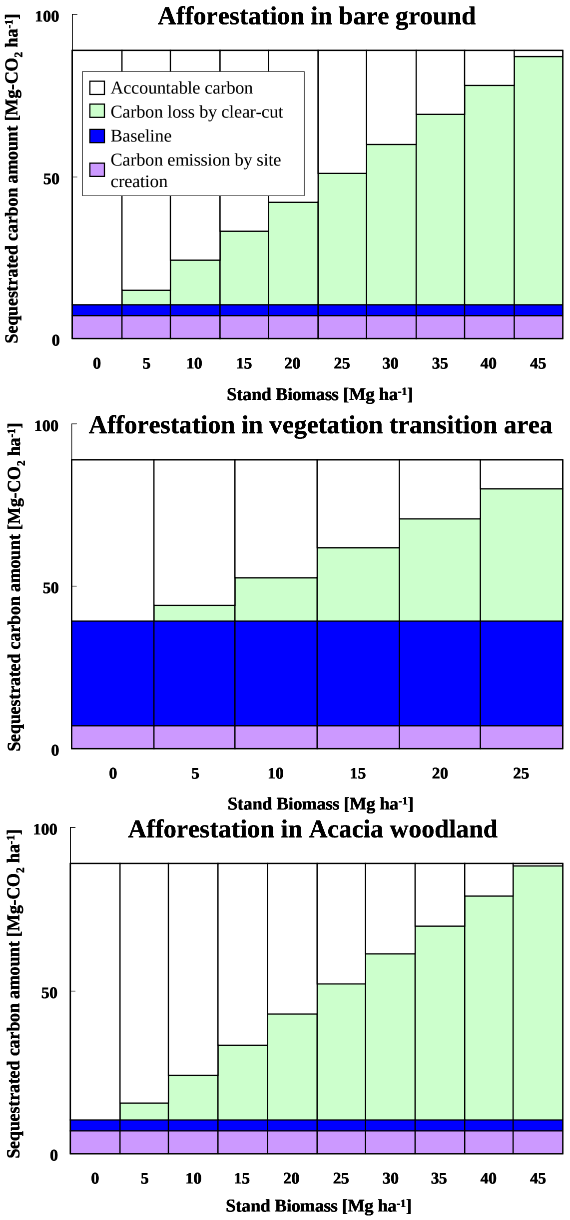

Fig. 1. Estimation results of sequestered CO_2 amount per hectare and its allocation by arid land afforestation

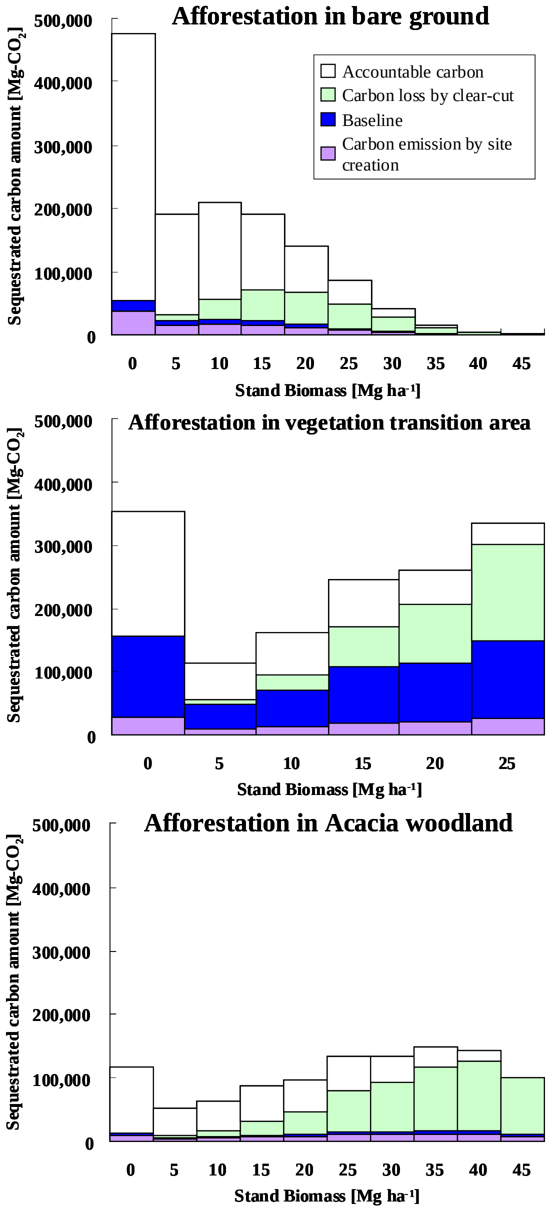

Fig. 2. Estimation results of total sequestered CO_2 amount and its allocation by arid land afforestation.

Acacia woodland. However, in all original vegetation type, the proportion of carbon loss by afforestation site creation was quite high. This carbon loss means that lot's of trees are cut and disposed in vain for afforestation site creation. Thus, as mentioned in Tahara *et al*. (2009), these biomass should be efficiently utilized as another carbon mitigation activity such as fuel production and electric generation. Therefore, this type of arid land afforestation must be carried out combined with another carbon mitigation activity using woody biomass.

By using equation (1) including afforestation applicable area, total sequestered carbon amount inside research area was estimated in each original vegetation on **Figure 2**. From this result, afforestation in bare ground earned large accountable carbon amount (964,000 Mg-CO_2). Since distribution area was not so large, total accountable carbon amount in *Acacia* woodland was relatively low (428,000 Mg-CO_2), but not negligible amount. That was because most of the *Acacia* woodland originally had a certain amount of carbon as woody biomass. On the other hand, the accountable carbon amount per hectare in vegetation transition area was very small but nearly similar accountable carbon amount to that of *Acacia* woodland was earned by afforestation because of its large distribution area (481,000 Mg-CO_2). Thus, even the carbon sequestration efficiency was low in vegetation transition area, afforestation in this area was not also negligible, either. From the results on Figures 1 and 2, afforestation in this research area should be carried out primarily in bare ground followed by *Acacia* woodland and vegetation transition area, in that order.

Assuming that all the afforestation applicable area can be used for afforestation, 44,000 ha of area in 230,000 ha research area will be used as afforestation site, resulted in 1.96×10^6 Mg-CO_2 of carbon will be sequestered in 30 years. This sequestered carbon amount corresponds to 0.16% of CO_2 emission amount in Japan in 2008 (1.21×10^9 Mg-CO_2). Considering this sequestered CO_2 amount, the contribution of arid land afforestation in this research area is negligible to CO_2 reduction of Japan. Therefore, other improvements should be necessary to maximize carbon credit earning.

One of the considered improvement methods was to create afforestation site consisting of mono-specific trees of *Eucalyptus camaldulensis* which had the fastest growth rate with the highest survival ratio. By trial calculation, estimated values of sequestered CO_2 amount per hectare and total sequestered CO_2 amount of *E. camaldulensis* mono -specific afforestation overcame those of above mentioned data. In particular, 54,000 ha of area in 230,000 ha research area will be used as afforestation site, and then 1.07×10^7 Mg-CO_2 of carbon will be sequestered in 30 years. This sequestered carbon amount corresponds to 0.88% of CO_2 emission amount in Japan in 2008. Therefore, not so huge amount of CO_2 will be sequestered in restricted area. To fulfill the aim of Japan which is 25% reduction of its CO_2 emission, more improvement or other carbon mitigation activities should be carried out in the future.

4. Conclusion

This study shows that the total sequestered carbon amount by arid land afforestation corresponds to 0.16% or 0.88% of CO_2 emission amount in Japan in 2008, depending on type of afforestation. However, these results revealed that sequestered CO_2 amount was not enough for carbon mitigation in Japan. To acquire enough carbon mitigation amount by afforestation, more improvements and other methods must be developed in future studies.

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