Salal in Old Growth Forests:

The Significance of Gaps in Understory Carbon Balance

With and examination of

The Link between Climate Change and Rural Livelihoods in Developing Countries:

An Opportunity for Latin America

By

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Gaps in the forest canopy allow more light to reach the understory. Since light in the understory is heterogeneous, understanding the physiological processes in gaps and non-gaps will improve estimates of carbon balance. This research outlines an approach for defining carbon balance for Salal (*Gaultheria shallon* Pursh.), a dominant understory shrub in Pacific Northwest old growth forests, growing in gaps and non-gaps.

The carbon balance of salal foliage was estimated using a three-step approach. Ambient photosynthesis of salal was surveyed in gaps and non-gaps using a LiCor Photosynthetic Gas Exchange System. The LAI and percent cover of salal in gaps and non-gaps was measured using a species/area curve and the line intercept method. Finally, leaf-based measurements were scaled to determine stand-level carbon use of salal in and out of gaps.

I hypothesized that photosynthetic capacity and respiration value differences between gap and non-gap salal foliage could be accounted for by water potential and nitrogen content measurements. To further characterize salal in gaps and non-gaps in the understory, sun/shade leaf characteristics such as leaf mass to leaf area ratios, light curves and A/C_i curves were compared.

Scaling from individual plant based estimates to stand-level estimates show the importance of gaps in the understory carbon balance. While salal covers the forest floor equally, the multileveled leaf-canopy of salal in gaps and the higher photosynthetic capacity of salal foliage in gaps contribute to the larger carbon balance role that salal foliage in gaps has when compared to salal foliage in non-gaps.

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I understand that my thesis will become part of the collection of Bioresource Research. My signature below authorizes release of my thesis to any reader upon request. I also affirm that the work represented in this Thesis is my own work.

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Table of Contents

List of Figures

List of Tables

Appendix

Appendix **Page**

Chapter 1.

1. Introduction

Climate change has drawn increased attention since the 1800's when Fourier made physical calculations and speculated that human activities could impact the climate (Boehmer-Christiansen 1999). Arrhenius also predicted a 4-6°C increase in air temperature and the concept of greenhouse effect was born (Boehmer-Christiansen 1999). International interest in climate change grew and in 1988, the Intergovernmental Panel on Climate Change (IPCC) was established and contributed to the development of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. In 1997, at the UNFCCC, the Kyoto Protocol was drafted to provide guidelines designed to reduce emission of anthropogenic greenhouse gases associated with climate change (Bureau of Oceans and International Environmental and Science Affairs 1998). As a result of the Kyoto Protocol, research on the global carbon dioxide (CO_2) budget and forestry management to alter the concentration of atmospheric CO_2, a greenhouse gas, has been reinforced.

This thesis focuses on two issues related to carbon assimilation by forests. In chapter two of this thesis, an estimate of the carbon balance of salal foliage in and out of gaps in an old growth forest is made. Understanding how forest canopy structure relates to carbon use in the understory is a useful management tool as well as a step toward more inclusive carbon budgets.

Estimates of the role of forests in the global carbon cycle were made, and results of this and other research show the importance of proper forest management and preservation as a way to mitigate CO_2 emissions. The third chapter of this thesis focuses on how the partnerships between industrialized nations and developing countries have formed to mitigate carbon dioxide emission by changing the relationships between poor rural communities and their forest resources.

Taken together, the chapters show that the technologies and approaches necessary to understand linkages between forest, carbon, and human activity are known. With the integration of this knowledge, solutions can be found to mitigate the increasing concentrations of atmospheric CO_2.

Chapter 2. Carbon balance of salal foliage in old growth forests

1. Introduction

1.1 Carbon balance. The earth's atmospheric CO_2 level has increased by 30% since pre-industrial times (Manning et al. 1997). Much of the increase is due to human activities, such as the burning of fossil fuels and deforestation (Chatterjee 1999). This increase in atmospheric CO_2 is widely accepted to be a cause of global climate change. Effects of global climate change include shifts in weather patterns, shifts in pest and disease ranges, and melting of the ice caps with subsequent rising of sea level. These effects threaten food and fiber production, small island stability and human health (Parry et al. 1999).

The increase in atmospheric CO_2 will directly affect the physiological processes and ecology of terrestrial plants. Currently CO_2 is a limiting substrate of C_3 photosynthesis. As CO_2 becomes less limiting, photosynthetic activity may increase at the plant and landscape level (Hsiao et al. 1999). How individual plant species or plant communities will be affected by increasing atmospheric CO_2 concentrations is not clear (Murray 1997). For example, as plant photosynthesis increases with increasing CO_2 concentrations, plants will need more water and nutrients (Hsiao et al. 1999 and Murray 1997). In the long run, increasing CO_2 concentrations will change plant community dynamics, succession, competition and evolution (Field 1999 and Selvi 1997).

Determining and quantifying the sources (net emitters) and sinks (net absorbers) of CO_2 is integral to completing the picture of our biogeophysical environment. Terrestrial plants are both a source and sink of CO_2 (Ciesla 1995). In general, mature stands of forest are considered carbon neutral or weak carbon sinks because their exchange of CO_2 with the atmosphere is equal or less than the CO_2 they assimilate. However, when forests are disturbed or destroyed by pests, disease, fire, and humans, the carbon that was tied up in the forest rapidly decomposes and is released into the atmosphere as CO_2 (Ciesla 1995). Upon reforestation, the site remains a net source of CO_2 until trees grow large enough and gain carbon fast enough to balance CO_2 emitted from soils, decaying wood and debris. In the Pacific Northwest, Douglas fir forests can become CO_2 sinks at an age of 30 or more years (Janisch and Harmon 2002)

Within a complex forest ecosystem, the age of the forest and its species are important factors in determining its carbon balance. The majority of carbon balance research in forests has focused on trees or whole stands of forest, but understory carbon balance research is rare. Although the carbon balance of understory vegetation is typically 10% or less of that used by trees (Turner et al. 1995), the understory warrants study. Understanding how understory species and environment contribute to the carbon cycle will provide data for forest management strategies and allow estimates to be made on the impact of understory disturbance on forest carbon balance.

1.2 Salal in Gaps. Gaps in the canopy, caused by windfall or tree death, influence the understory environment. The principal limitation of understory productivity is light (Walters and Reich 1997, McGuire et al. 2001), with other possible limitations including water and nitrogen availability (Walters and Reich 1997, McGuire et al. 2001). Gap formation increases the quantity and quality of light reaching the forest floor (Canham et al. 1990, McGuire et al. 2001), which in turn affects understory species distribution, cover and productivity. In a study of gap regeneration succession, eight understory species in a hemlock community showed higher cover in a gap than in a closed canopy (Rankin and Tramer 2002).

Salal (*Gaultheria shallon* Pursh) is a clonal evergreen shrub found in coastal forests from central California to Southern Alaska. While salal is a source of forage for deer, it competes with Douglas-fir for water and nutrients in the understory, and inhibits establishment of western hemlock (Huffman and Tappeiner 1997) and bigleaf maple (Fried et al. 1988). The cover, morphology and productivity of salal are strongly related to overstory canopy density and understory light environment (Huffman et al. 1994).

The density of the canopy overstory affects the morphology and physiology of salal. In Pacific Northwest forests, salal can have a leaf area index (LAI), a measurement of the estimated area of foliage per unit ground area, of up to 0.2 but at the Canopy Crane research site, salal has a LAI of 0.15 (Thomas and Winner 2000).

When comparing gap and non-gap plants of one species, a comparison between sun-leaf and shade-leaf characteristics is useful for explaining physiological and morphological differences attributable to plants growing in low and high light environments. Sun leaves have greater leaf dry mass per area (LMA) and are thicker than shade leaves (Lamber et al. 1998, Larcher 1995). The photosynthetic capacity (A), ribulose-1,5-biphosphate (RuBP) carboxylation and electron transport rates, dark respiration and nitrogen content (N), when calculated on an area basis are greater for sun leaves than for shade leaves (Lamber et al. 1998, Larcher 1995).

1.3 Goals and objectives. The general goal of this project is to derive a leaf-area based estimation of the carbon balance of salal foliage in the understory of an old growth forest. The estimated carbon balance is made through three steps:

1. *Survey the photosynthetic rates of salal in gaps and non-gaps.* A survey of photosynthetic rates is important to determine if salal gains carbon at the same rate in and out of gaps. Because of the higher light environment in gaps, it is likely that salal in gaps will have higher rates of photosynthesis than salal in non-gaps.

2. *Survey the LAI and canopy coverage of salal growing in and out of gaps.* LAI and canopy cover surveys will determine how salal is distributed throughout the understory. The LAI and canopy cover surveys will test the hypothesis that salal is denser and covers more ground area in gaps than in non-gaps.

3. *Determine the differences in stand-level carbon balance of salal foliage in gaps and non-gaps.* Data from measurements of photosynthesis, respiration and the distribution of foliage in and out of gaps will be used to calculate stand-level carbon balance of salal foliage. The calculation is done over a range of hypothetical light conditions in gaps to provide estimates of maximum and minimum values for the carbon balance of salal foliage.

2. Site characteristics

This study was conducted at the Wind River Canopy Crane Research Facility (WRCCRF) located within the USFS Gifford Pinchot National Forest in the Thorton T. Munger Research Natural Area, northwest of Carson, Washington. At 335 m elevation, in the southwestern Cascade Mountain Range, the surrounding topography consists of gentle slopes. With a temperate wet winter and dry summer climate, WRCCRF receives over 90% of its 2,528 mm of annual precipitation between the months of August through May. The annual snowfall of 2,330 mm occurs from November until March. The soils are shotty loamy sands and sandy loams formed in 2-3 m of volcanic ejecta over basalt bedrock.

The canopy of this protected 4.0 ha temperate old-growth coniferous rainforest is dominated by 400-500 yr old Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), western red cedar (*Thuja plicata* (Donn ex D. Don)), western white pine (*Pinus monticola* (Dougl. ex D. Don)), pacific silver fir (*Abies amabilis* (Dougl.) Forbes), and grand fir (*Abies grandis*) also grow in the site. The understory is dominated by vine maple (*Acer circinatum*), salal (*Gaultheria shallon* Pursh), and Oregon grape (*Berberis nervosa* Pursh). Other characteristic understory species include blackberry (*Rubis ursinus*), cascara buckthorn (*Rhamnus pershiana* DC.), several huckleberry species (*vaccinium*) as well as trillium (*Trillium ovatum* Pursh) and vanilla leaf (*Achlys triphylla* (Sm.) DC.).

The WRCCRF limits research impact in this old growth forest by holding to standards of strict research conduct. Rules and regulations are in place to minimize all human impact on the site. Destructive sampling methods are turned in with the proposal and reviewed by a scientific panel, that assures research methods will not change the integrity of the forest. An aboveground boardwalk protects the understory from trampling by researchers. On-site meteorological instruments allow scientists access to a precise historical and current record of meteorological data. In addition to these benefits, the integrative and cooperative atmosphere between scientists and staff make WRCCRF an ideal place for research on old growth forests and the associated understory.

3. Materials and Methods

3.1 Sampling. Six study plots, consisting of three gap plots and three non-gap plots, were located in the 4.0 ha plot covered by the crane. Density and canopy cover data were used to determine plot locations. Non-gap plots had less dense canopy coverage than gap plots that had 70% sky cover or more. Gap plots had more dense canopy coverage with approximately 0-40% sky coverage. Minimum understory plot size was approximately 10 m x10 m.

The understory of gap plots was dominated salal, vine maple and red huckleberry. Non-gap plots were dominated by a moss carpet, Oregon grape, trillium and vanilla leaf. Salal growing in the gap plots ranged from 0.3-1.0 m tall with dense foliage. Salal growing in the non-gap plots ranged from 0.0-0.3 m tall with sparse foliage.

Within each plot, three salal plants were individually marked for gas exchange measurements. Plants were chosen by their location within the plot. Plants chosen for this study were representative of healthy individuals. Plant location within the plot was based upon light availability, non-gap plots having the least amount of light available to the sample plants, gap plots having the greatest amount of light available to them. The same plots were used throughout the investigation. The same plants were used throughout the investigation for non-destructive gas-exchange measurements.

3.2 Gas exchange. To compare carbon balance between salal leaves growing in and out of gaps, gas exchange measurements were collected during three trips: August 10-11, 2000, June 23-24, 2001 and July 14-15, 2001 using a LiCor 6400 Portable Photosynthetic Gas Exchange System (LI-COR Inc., Lincoln, NB). To survey photosynthesis, the console was programmed to hold environmental conditions at desired light, temperature, humidity and CO_2 concentrations in the cuvette. A mature salal leaf was placed in the cuvette and after a few minutes, after conditions and physiology were stable, a measurement was recorded. During all photosynthetic survey measurements the atmospheric CO_2 concentration was set at 350 ppm, the leaf temperature was set at the ambient level, and the humidity was set at ambient level or no higher than 60% to prevent water condensing in the instrument. An LED red 6400-02 #SI-355 light source was used during the August and June trip. In July, a LiCor 6400-02B RedBlue #SI-827 light source was used.

To determine how light levels affected photosynthesis of gap and non-gap leaves, photosynthesis was measured at zero, the ambient level that ranged from 20 to 800 $\mu E\ m^{-2}\ s^{-1}$, and the high level, 1200 $\mu E\ m^{-2}\ s^{-1}$. Photosynthesis at three light levels was measured on all three trips. One data set was completed in August 2000. The second data set was completed in June 2001 and July 2001. Data sets were recorded off of three leaves from two plants in each of the three gap plots and three non-gap plots.

Photosynthetic light response curves were used to compare light use between salal leaves in and out of gaps. The photosynthetic response of salal to increasing light levels was measured at 0, 10, 15, 25, 35, 50, 75, 100, 200, 400, 800 and 1200 $\mu E\ m^{-2}\ s^{-1}$. Photosynthetic light response curves were completed during trip one and trip three, for two complete sets of data. Each set of data consisted of three photosynthetic light responses in gaps and threes curves in non-gaps.

Light response curves are measured by a LiCor 6400 that employs a program to allow an increase in light level in programmed increments, stabilize and then record after zeroing the conditions. A stabilization time of 100 – 300 s was used before zeroing and recording the measurement.

To compare internal CO_2 use between salal leaves in and out of gaps, the photosynthetic response to internal CO_2 (C_i) concentrations were measured by setting atmospheric CO_2 (C_a) concentrations at 0, 50, 75, 100, 200, 350, 500, 100 and 1500 ppm during trips in August 2000 and July 2001, completing two sets of data. Each set of data included A response to C_i were replicated three times for each C_a level on one leaf for each of three plants in one gap plot and one non-gap plot.

3.3 <u>LAI and LMA</u>. The LAI was measured for salal growing in and out of gaps to determine carbon balance in low and high light environments. Leaves were clipped in 100 cm by 100 cm quadrats placed on alternating sides of a 5 m transect. The transects were placed in three gap plots and three non-gap plots in a site adjacent to the original crane site to avoid destructive harvest in the crane circle. Partial leaves were alternately clipped or left. The area of clipped leaves per quadrat was measured with a UMAX Astra 1220S scanner. LAI was determined as total leaf area per m^2 of ground.

The LMA was determined as leaf mass to leaf area. Leaves collected by quadrat for the LAI measurements were dried and weighed for LMA.

3.4 Measuring canopy coverage for gaps and non-gaps. In the adjacent, identical 4.0 ha plot 18 transects, each 20 m long, were placed in the understory. The length of salal occurrence, in a gap or in a non-gap along each transect was recorded. The percent of transect interception by salal was determine for each transect and cumulatively averaged to determine canopy coverage for the site.

3.5 Water potential. Water potential was measured *in situ* to determine if water stress could explain differences between photosynthesis of salal in and out of gaps. A pressure bomb (PMS Instruments, Corvallis, OR) was used for predawn (4-6am), midmorning (9-1 am) and afternoon (12-2pm) measurements during all trips. Water potential was measured in August, 2000 on one leaf from four plants for each of the six plots, three gap and three non-gap. Water potential in June 2001 was measured on two leaves from two plants for each of the six plots, gap and non-gap. Water potential in July 2001 was measured for two leaves of two plants in the plots that were being worked in. All samples were collected, stored in airtight plastic bags and then put on ice.

3.6 Nitrogen content. Nitrogen content was measured to explain photosynthetic rates between salal in gaps and in non-gaps. A subsample of 32 leaves from the water potential measurements was analyzed for N content.

In August, 2000 and June, 2001, 18 leaves were chosen: 3 leaves from each of the three gap plots, and 3 leaves from each of the three non-gap plots. The Kjeldahl method for determining total foliar N content was used at the OSU Forage Testing Laboratory to measure the percent N on a mass basis. The percent N on a mass basis was later converted to percent N on a leaf area basis.

3.7 Statistical analysis. Data Desk version 4.2 (Data Descriptions Inc., Ithaca, New York) in the Macintosh format was used to perform ANOVA method statistical analysis. For the photosynthetic rate survey of salal at three light levels, explanatory variables were trip, plot, plant, leaf, light level and gap or non-gap environment. The response variable was the photosynthetic rate. For water potential analysis the explanatory variables: trip, site, time of day, plant, leaf and gap or non-gap environment were included. Water potential values were the response variable. Explanatory variables used for the photosynthetic response to light analysis were: trip, repetition, light level and gap and non-gap environment. The response variable was photosynthetic rate. To analyze the photosynthetic response to internal CO_2 concentrations trip, site, repetition, internal CO_2 concentrations and gap and non-gap environment were explanatory variables. The response variable was photosynthetic rate.

3.8 Scaling. In order to determine the significance of gaps on the carbon balance of salal at a stand level, leaf-area based photosynthetic measurements as well as LAI and canopy cover results were scaled to the stand level. We assumed that, due to snow cover from November through March, salal is not photosynthetically active during the winter. However, the snow typically clears in

March and the remaining growing season, which we used for estimating the carbon balance, is April through October. Based on a compilation of light data from a light sensor, situated 2 m above the forest floor in a non-gap environment, we assumed a six-hour photosynthetic active period during the day and an 18-hour period of night respiration.

Non-gap stand level carbon balance estimates of salal foliage used the mean light level (21 $\mu E\ m^{-2}\ s^{-1}$) and the photosynthetic rate at that level (1.2 μmoles $CO_2\ m^{-2}\ s^{-1}$). The rate of photosynthesis was converted to gC $ha^{-1}\ h^{-1}$, scaled up to a yearly estimate and multiplied by the LAI and %cover for non-gap salal. Night-time respiration values (0.24 μmoles $CO_2\ m^{-2}\ s^{-1}$) were converted to gC $ha^{-1}\ h^{-1}$, scaled up to a yearly estimate, multiplied by the LAI and %cover and then subtracted from the assimilation values to obtain the carbon balance of salal foliage growing in non-gaps.

The carbon balance of salal foliage growing in gaps was made, assuming a low light (21 $\mu E\ m^{-2}\ s^{-1}$) base photosynthetic rate (1.1 μmoles $CO_2\ m^{-2}\ s^{-1}$) and then substituting 1 h to 4 h of light saturated photosynthesis (6.5 μmoles $CO_2\ m^{-2}\ s^{-1}$) from the 6 h total. Night-time respiration (0.38 μmoles $CO_2\ m^{-2}\ s^{-1}$) was scaled up to stand and yearly levels and then subtracted from the assimilation values of salal foliage in gaps to estimate the carbon balance.

4. Results

4.1 Photosynthesis and respiration. Photosynthesis measurements support the sun/shade leaf model with salal leaves in gaps having higher photosynthetic rates than non-gaps leaves. The rate of net ambient CO_2 assimilation for salal in gaps is 3.5 μmoles CO_2 m^{-2} s^{-1}, which is almost three times as great as net CO_2 assimilation for salal out of gaps, 1.1 μmoles CO_2 m^{-2} s^{-1} (Figure 1). However, the light levels differed with mean ambient gap light levels at 159 μE m^{-2} s^{-1} and ambient non-gap levels at 21 μE m^{-2} s^{-1}. The photosynthetic differences between gap and non-gap salal plants are consistent at saturating light levels. At 1200 μE m^{-2} s^{-1}, photosynthesis for salal leaves in gaps was 6.5 μmoles CO_2 m^{-2} s^{-1}, of salal growing out of gaps, 3.1 μmoles CO_2 m^{-2} s^{-1} (Figure 1).

Differences between light saturated net photosynthesis for gap and non-gap leaves were also found in the light response curve (Figure 2A). Maximum rate of assimilation for salal in gaps is greater than salal out of gaps. Salal in gaps assimilates at 6.6 μmoles CO_2 m^{-2} s^{-1} and in non-gaps, 3.1 μmoles CO_2 m^{-2} s^{-1}. Even though salal in gaps has a photosynthetic capacity twice as great as salal in non-gaps, salal in gaps need five times the intensity of light to reach saturation. Light saturation of salal foliage, demonstrated where the curve begins to level, is approximately 250 μE m^{-2} s^{-1} for leaves growing in gaps and 50 μE m^{-2} s^{-1} for non-gap foliage. The differences in photosynthetic activity did not extend to their compensation points. The points where X equals zero, for salal in gaps and out of gaps were not statistically different (Figure 2B). The quantum yield of salal in gaps and out of gaps, represented by the slope of the line between the x equals zero and 25 μE m^{-2} s^{-1} points, is not statistically different (Figure 2B). Respiration values as well are not statistically different (Figure 2B), although gap leaves have higher mean respiration than means for non-gap plants (Figure 1).

Photosynthetic responses of gap and non-gap salal to increasing C_i during August 2000 (Figure 3A) and June 2001 (Figure 3B) trips are similar. A_{max} for salal is approximately twice that in gaps than in non-gaps for August respectively, 12 and 7.4 μmoles CO_2 m^{-2} s^{-1} and June respectively 7.7 and 3.2 μmoles CO_2 m^{-2} s^{-1}. RuBP carboxlyation, which is represented in the initial slope, between C_i of 300 and 100 ppm, was not different between gap and non-gap salal (Figure 3).

Foliar respiration for salal in gaps and out of gaps supports the sun/shade leaf model with salal leaves in gaps having higher respiration rates than salal leaves in non-gaps. Foliar respiration for leaves in gaps was 0.38 μmoles CO_2 m^{-2} s^{-1} and was higher than for salal in non-gaps, 0.24 μmoles CO_2 m^{-2} s^{-1} (Figure 1).

4.2 Water potential. Water potential measurements shows that water limitation cannot explain photosynthetic differences between gap and non-gap salal (Figure 4). Water stress rarely exceeded -1 MPa, so plants did not achieve severe water stress even in August. Only in August, during midmorning, did plants in gaps have more negative water potential than did non-gap plants, even though water stress increased through the course of the day for all plants.

4.3 N content and LMA. The N content of salal was measured because foliar N content on an area basis of sun and shade leaves increases with A_{max} (Lambers 1998). Photosynthetic differences between salal in gaps and non-gaps, can be explained by N content on an area basis with N being greater in gap leaves that in non-gap leaves (Table 1). Mass-based measurements of N content for salal leaves were converted to area based measurement using leaf mass to area ratios (LMA). Salal gap leaves tend to have greater mass per area of 80 g m^{-2} than non-gap leaves, 60 g m^{-2}. N content of salal leaves in gaps is 0.83 gN m^{-2} while salal leaves in non-gaps contain 0.58 g m^{-2} of N. Therefore, differences in foliar N content between gap and non-gap salal leaves can explain some of the differences in photosynthesis that were observed.

4.4 LAI and canopy cover results. The amount of leaf area per ground area, the leaf area index (LAI), of salal was measured to determine the density of salal leaves that grow in the gaps and non-gaps in order to calculate stand-level carbon balance of salal. Salal growing in gaps has many more layers of leaf canopy than non-gap salal. The LAI of salal in gaps was 2.5, a value ten times greater than the LAI of salal in non-gaps, 0.25 (Table 1).

The canopy coverage of salal was measured to be able to calculate stand-level carbon use. Surprisingly, salal had about the same coverage throughout the understory constituting a canopy cover of salal in gaps of 5.5% and in non-gaps as 6.0% (Table 1).

4.5 Stand–level carbon balance in gaps and non-gaps. In order to determine the significance of gaps in the carbon storage capacity of salal, leaf area and photosynthetic measurements were scaled up to a stand estimate (Table 3 and 4), revealing that non-gap salal incorporates, about 0.0473 tC $ha^{-1}yr^{-1}$, in comparison to gap salal with two hours of light saturation per day at 2.42 tC $ha^{-1} yr^{-1}$. Estimates of the carbon use of salal in gaps were made assuming periods of light saturation for one to four hours (Table 3 and 4) which ranged from 1.20 tC $ha^{-1} yr^{-1}$ to 4.92 tC $ha^{-1} yr^{-1}$.

5. Discussion

5.1 Account for the physiological differences. The distribution of N explains differences in photosynthesis measured in and out of gaps, yet more questions remain. For example, what causes the differences of N content of salal in and out of gaps? More research is needed to determine the relationship between N and gap ecology and to investigate the difference between the investment towards N acquisition of salal in gaps and non-gaps. In addition, more research is needed to understand how salal acquires water and resists extreme water stress in the height of summer.

While many of our results support the sun/shade model, there is room for future work at all levels: structural, biochemical and gas exchange. Measurements of leaf thickness, stomatal density, chlorophyll a/b ratio, rubisco per area and well as better control of time of day and seasonal effects on gas exchange measurements could be explored in the future.

5.2 Carbon uptake. This three-step approach for estimating carbon balance in the understory can be applied to other understory species. The process of scaling a leaf-based estimate is low-cost, relatively quick and gives a broad picture of how the understory relates to the ecosystem carbon relations.

The strong differences between ambient photosynthetic rates in gaps and non-gaps support the need to account for understory heterogeneity in understory carbon budget estimates. Other plant species that demonstrate distinctive sun/shade leaf characteristics include beech (*Fagus sylvatica*) and ivy (*Hedera helix*) (Larcher 1995), brittle bush (*Encelia farinosa*) (Zhang 1995), and wall lettuce (*Mycelis muralis*) (Clabby 1997). The occurrence and characteristics of gaps differs by forest age, structure and species so that for each understory carbon budget the uniqueness of the system must be included at several levels.

The study presented here provides an estimate of the carbon balance of salal foliage. However, to provide a more complete picture, woody and root respiration values from other research could be used to complete an estimate of the carbon balance of salal plants in the understory.

Instantaneous photosynthetic measurements were scaled for a yearly average. Ignoring diurnal and seasonal patterns, daily weather, sun fleck variation and afternoon stomatal closure for yearly estimations may results in estimation errors (Naumburg and Ellsworth 2002). The succession of gaps was ignored. As the canopy fills in the gap, pioneer understory species, which cannot adapt become less productive or die.

The capacity of gap salal to store carbon is greater than non-gap salal. Understanding how the understory plant species respond to gaps, created by natural forces or management practices, is critical in calculating carbon balance and determining the costs and benefits of forest management techniques.

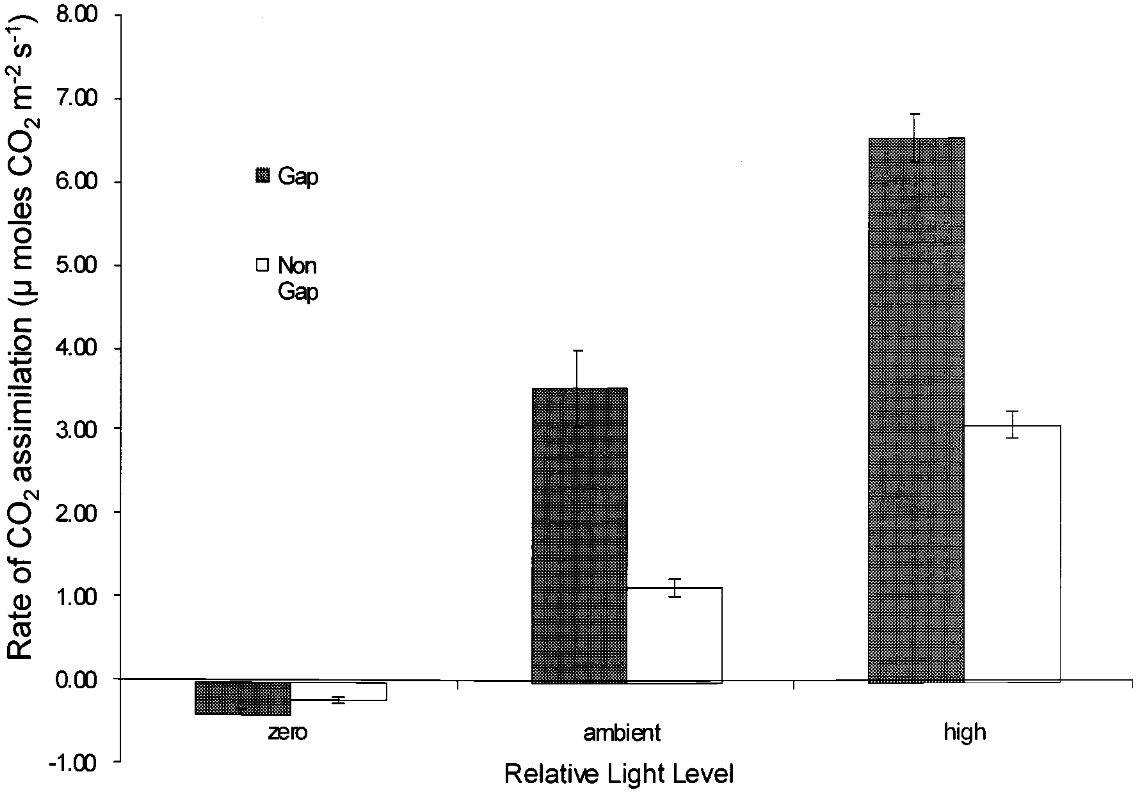

Fig. 1. Assimilation values measured in gap and non-gaps across three light levels. Values combined from August 2000 and June 2001. High light level was 1200 µE m^{-2} s^{-1}. Ambient light level ranged from 20-800 µE m^{-2} s^{-1} . At all light levels, salal in gaps assimilate more CO_2 and have greater rate of respiration that salal in non-gaps. Values are means ± 1 Se. Significant differences were due to light treatment ($P \leq .0001$) and gap/non-gap environment ($P \leq .0002$).

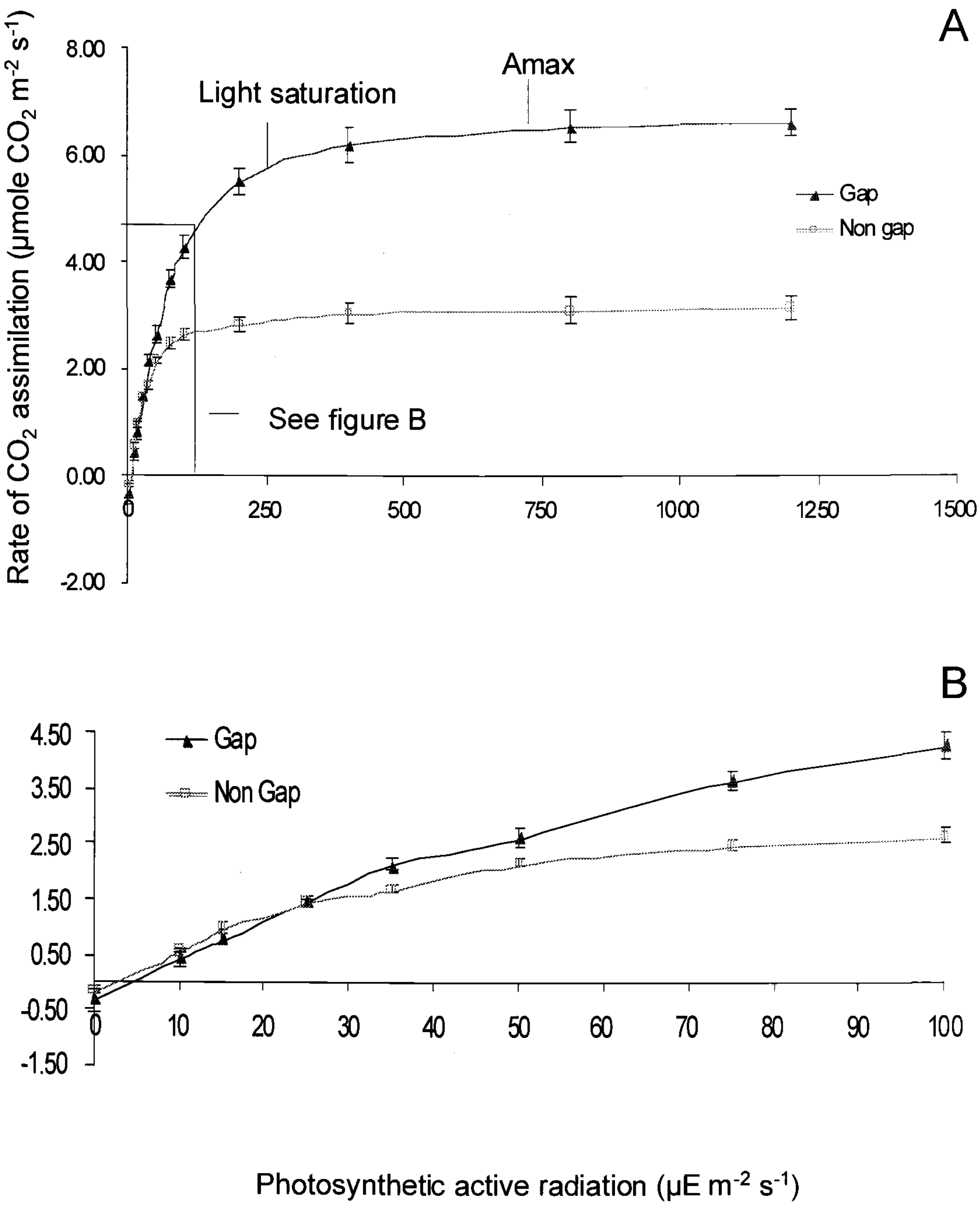

Fig. 2A and B. Values of CO_2 assimilation of salal growing in gaps and out of gaps in response to increasing light. Data from August 2000 and June 20001 are combined in this graph. Maximum assimilation rate for salal growing in gaps is approximately twice as great as salal growing out of gaps. Light saturation for salal in gaps occurs at approximately 250 µE m^{-2} s^{-1} while light saturation for salal out of gaps is at 50 µE m^{-2} s^{-1}. Figure B shows that light compensation points where X=0 and quantum yield of salal between salal in and out of gaps is similar. Values are means ± 1Se.

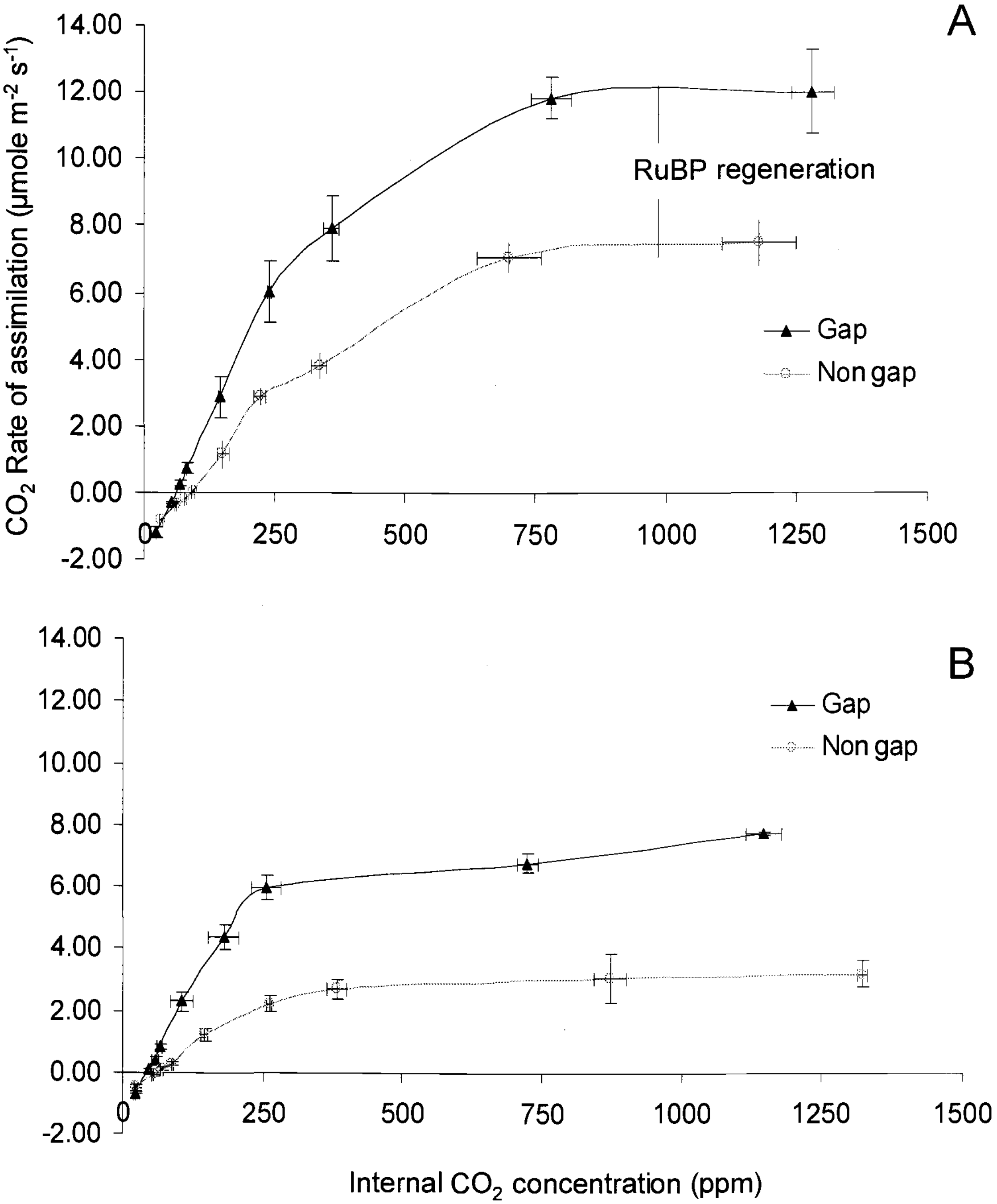

Fig. 3A and B. Rates of CO_2 assimilation in response to internal CO_2 concentrations of salal plants growing in and out of gaps for August 2000 (Fig. 3A) and June 2001 (Fig.3B). The carboxylation efficiency of salal in gaps and out of gaps is not significantly different as seen in the Ci =125-300 range. The rate of RuBP regeneration for salal in gaps is greater than RuBP regeneration out of gaps as seen in the level part of the curve. Values are means ± 1 Se.

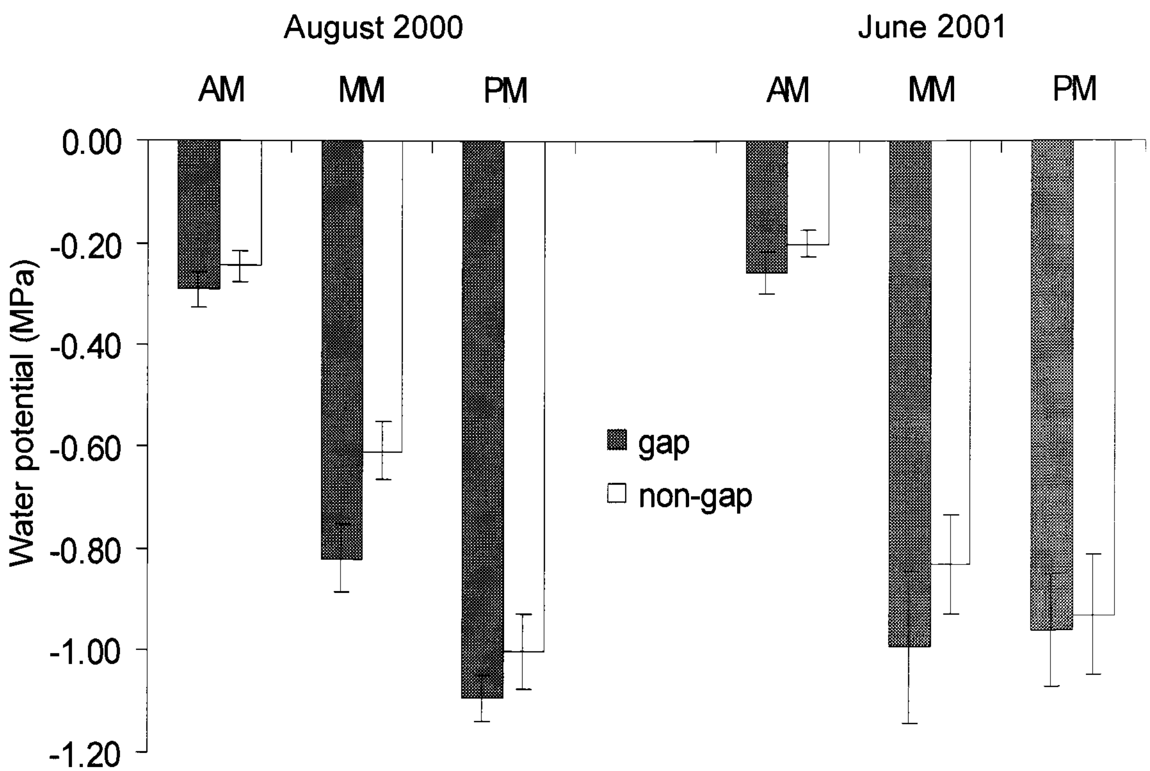

Fig. 4. Water Potential values measured in gap and non-gaps at three times during the day: early morning (AM), midmorning (MM) and afternoon (PM). Water potential measurements taken in July 2001 are statistically the same as August 2000 data. There were no statistically significant results due to gap or non-gap environment. There was a time of day effect during both trips ($P \leq .0001$). Values are means ± 1 Se.

Table 1. Summary of % nitrogen (N_{mass}), leaf mass to leaf area ratio (LMA), nitrogen (N_{area}), leaf area index (LAI), and % canopy cover results. Mean values ± 1Se.

Measurement	Gap	Non-gap
N_{mass} ($gN\ g^{-1}$)	1.0 ± 0.03	0.98 ± 0.038
LMA ($g\ m^{-2}$)	80 ± 3.5	60 ± 5.3
N_{area} ($gN\ m^{-2}$)	0.85 ± 0.011	0.60 ± 0.015
LAI	2.5 ± 0.078	0.18 ± 0.014
% Canopy cover	5.5 ± 0.34	6.2 ± 0.29

Table 2. Modeling carbon balance of salal foliage in gaps and in non-gaps.

1. $C_b = A_{shade/max} - R$

where:

C_b is the carbon balance of salal foliage in kgC ha^{-1} yr^{-1}

A is the rate of photosynthesis for gap or non-gap plants in kgC ha^{-1} yr^{-1}, assuming a 6 h light day^{-1} with 213 day yr^{-1}snowfree. The calculation for non-gap plants only uses A_{shade}. The calculation for gap salal foliage substitutes A_{max} for 1-4 h day^{-1} of A_{shade}.

A_{shade} is the rate of net photosynthesis at 21 µE m^{-2} s^{-1} in kgC ha^{-1} yr^{-1}.

A_{max} is the rate of net photosynthesis at 1200 µE m^{-2} s^{-1} in kgC ha-1 yr-1.

R is the rate of night-time respiration in kgC ha^{-1} yr^{-1}, assuming 18 h day^{-1} with 213 day yr^{-1}.

Table 3. Modeling carbon balance of salal foliage

	Ps μmole CO_2 m^{-2} s^{-1}	h day^{-1}	C_{gain} gC m^{-2} day^{-1}	C_{gain} gC m^{-2} yr^{-1}	C_{gain} kgC ha^{-1} yr^{-1}
Non-gap	1.2	6	0.311	66.2	113
Gap 1	1.1	5	0.238	50.6	63.5
	6.5	1	0.281	59.8	75.0
Gap 2	1.1	4	0.190	40.5	50.5
	6.5	2	0.562	120	149
Gap 3	1.1	3	0.143	30.5	38.2
	6.5	3	0.842	179	224
Gap 4	1.1	2	0.095	20.2	25.3
	6.5	4	1.12	239	299
	R μmole CO_2 m^{-2} s^{-1}				
Non-gap	-0.24	18	-0.187	-39.8	-68.1
Gap	-0.38	18	-0.0295	-62.8	-78.5

Note -To estimate non-gap carbon balance, the rate of photosynthesis at 21 μE m^{-2} s^{-1} (A_{shade}) was used for a 6 h day^{-1}. To estimate gap carbon balance, hours of photosynthesis at 1200 μE m^{-2} s^{-1} were substituted for hours of A_{shade}. Yearly estimates assumed 213 days of photosynthetic activity, when salal is not covered by snow. Assuming 95% non-gap salal environment and 5% gap salal environment, LAI for gaps (2.5) and non-gaps (0.18) were integrated into the stand level estimates.

Table 4. Stand level estimates of the carbon balance of salal foliage

Environment	Daytime Carbon Gain (A) (kgC ha^{-1} yr^{-1})	Nighttime Respiration (R) (kgC ha^{-1} yr^{-1})	Net Carbon balance = A-R (tC ha^{-1} yr^{-1})
Non-gap	113	68.1	44.9
Gap 1	139	78.5	60.5
Gap 2	200	78.5	122
Gap 3	262	78.5	184
Gap 4	324	78.5	246

Table 5. Sun/Shade leaf model results

Model characteristic	Sun leaf	Shade leaf	Gap and non-gap results consistent with sun/shade leaf model?
Photosynthetic capacity by area	high	low	Yes
Respiration Rate by area	high	low	Yes
Quantum Yield by area	same	same	Yes
Compensation Point by area	high	low	Inconclusive
RuBP carboxylation rate	high	low	Inconclusive
Nitrogen content % by area	high	low	Yes
LMA	high	low	Yes

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Chapter 3. The link between climate change and rural livelihoods

1. Introduction

1.1 Climate change. Climate change is a local, regional or large-scale change in the long-term average of temperature, precipitation, circulation, and related climatic variables (Gates 2002). Climate is key to the distribution of animals and plants as well as the formation of soils. Many factors can influence climate, but this paper will focus on an atmospheric factor, specifically carbon dioxide (CO_2), a greenhouse gas (GHG). An exponential increase in GHGs, especially CO_2 has been recorded since the industrial era due to the increased burning of fossil fuel (O'Neil 2001). However, during the 1980's attention grew on the destruction and burning of tropical rainforests as a source of atmospheric CO_2 (Myers 1991). The increase in concentrations of GHGs is forecasted to cause a rise in sea level, a shift in climate as well as shifts in pest and disease ranges (Ciesla 1995). In response to the effects of climate change, scientists and agencies worldwide have been organizing to find solutions to global climate change. One of the many proposed solutions is to manage forests to help mitigate CO_2 emissions and climate change.

1.2 Forests as carbon sources and sinks. Forests play a large role in the global carbon cycle. Forests store carbon above (vegetation and trees) and below ground (roots, liter, soil). As trees and vegetation photosynthesize and respire, CO_2 is exchanged with the atmosphere. Because forests have long-life spans and relatively large trees, forests can be carbon sinks (store carbon) (Ciesla 1995 and Brown in press). However, when forests are disturbed, cut down, burnt, blownover, or destroyed by pests or disease the stored CO_2 is released back into the atmosphere. If a greater amount of CO_2 is released than stored over a period of time, the forest is a carbon source (Ciesla 1995 and Brown in press). It is the capacity of a forest to act as a carbon sink that allowed forest management to be accepted as a CO_2 emission mitigating activity in international agreements.

1.3 International agenda. In the 1990's, climate change came to the forefront of international attention. The United Nations Convention on Environment and Development (UNCED) was held in Rio de Janeiro in 1992: Berlin in 1995, Kyoto in 1997, Buenos Aires in 1998, and The Hague in 2000. These conferences, which focused on global environmental problems, led to a protocol to lessen the threat of climate change by reducing emissions of GHGs.

The strategy of the Kyoto Protocol, an agreement between the UN Framework on Climate Change Parties, is to use global marketforces to reduce GHG emissions (Bureau of Oceans and International Environmental and Scientific Affairs 1998). The Protocol sets emission targets and timetables for individual countries to limit six GHGs, one of which is CO_2. Activities that absorb CO_2 from the atmosphere, such as afforestation, reforestation, and conservation have been accepted into the Protocol as a low-cost method for private sectors to reach their emission target. An emission credit trading system between participating countries can be used to meet emission targets, or partnerships can be made with developing countries to exchange carbon credits for clean technologies or development projects.

This alternative method of reducing emissions, through partnerships with developing countries, is described in the Kyoto Protocol as the Clean Development Mechanism (CDM).

1.4 Scope of the paper. International attention on climate change and the use of forests as carbon sinks (net absorbers of CO_2) to counter greenhouse gas emissions by industrialized nations through partnerships with developing countries may benefit rural communities in developing regions. Special focus will be placed on Latin America for its potentially large role in negating the effects of greenhouse gas emissions through sustainable forestry management.

1.4 Goals and objectives. Much research has been done on the cost effectiveness of different forest management practices to sequester CO_2. However the social and economical impacts of these forest managements on the local communities are different. For example, community plantation development requires the direct involvement of the community, which can affect the community structure and revenue. Forest preservation projects do not require direct involvement of the local community and can affect local resource access and business opportunities. The goal of this paper is to determine which forestry management strategy, community plantation development or preservation of forests, is most beneficial to local rural communities in Latin America through case-study analysis.

1. *Identify advantages and disadvantages of community tree plantations to the local people.* The advantages of direct community involvement are expected to out weight the disadvantages. The characteristics of the community plantation case-study will be assessed as a benefit or disadvantage based on the characteristic's effect, certainty, and duration.

2. *Identify the advantages and disadvantages of conservation forestry to the local people in Bolivia.* The advantages of preservation of forests will out weigh the disadvantages. The characteristics of the forest preservation case-study will be assessed as a benefit or disadvantage based on the characteristic's effect, certainty, and duration.

3. *Compare forestry practices to determine the best outcome for the locals.* Using a utilitarian approach by determining the duration and certainty of each advantage and disadvantage from the case study, we expect that plantation forestry management will yield more benefits to the local community than the forestry preservation project. Comparisons between the two management practices will be made based on the assessment of the minimum required characteristics that would constitute a community plantation project or preservation project.

2. Role of Latin American forests in the carbon cycle and livelihood use.

2.1 Carbon storage in tropical America. According to the 1995 FAO report, the world's forests are estimated to contain up to 80% of all above ground terrestrial carbon and approximately 40% of all below ground carbon equaling roughly 340 Pg (10^{15}g) C. Fifty-two percent of the world's forests lie in the tropical zone between 25° N and 25° S latitudes, which includes some Latin American countries (Brown 2002). Latin American tropical forests account for the largest estimated vegetation and soil carbon pool of 119 and 110 Pg respectively. The vegetation of tropical America stores 35% of the global carbon stored in forest vegetation. Of the 55% of global carbon stored in forest vegetation, 62% is stored in tropical forests with tropical America accounting for 35% of the 62% (Brown 2002). The soils of tropical America also store large amounts of carbon, compromising approximately 17% of all below ground forest carbon (Brown 2002). Overall, tropical America stores 52% of all above and belowground terrestrial forest carbon.

2.2 Latin American forest carbon flux. Current forestry management in the tropics releases 30% of the amount CO_2 that is release by the burning of fossil fuel worldwide (FAO 1993). During the 1980's, roughly 15.4 million ha yr^{-1} in the tropics were estimated to be lost, thus contributing to atmospheric CO_2 (FAO 1993). If the area left from these lost forests began to regenerate, the carbon lost could be regained. However, if the soils eroded or were impacted by improper logging, overgrazing, or cultivation, then the forest would not be able to regenerate, and more CO_2 would have been added to the atmosphere. Assuming regrowth, tropical forests are estimated to be a large net carbon source of 1.65 + - .4 Pg yr^{-1} (FAO 1993). According to this estimate, Latin American tropical forests account for a third of this carbon source, or a flux between -.5 and - .7 Pg yr^{-1} (Brown 2002).

2.3 Potential future role of tropical Latin America. The Kyoto Protocol proposes that forests can be managed to reduce atmospheric concentration of CO_2. One study using data from other worldwide carbon research, estimates that 60 Pg of carbon could be sequestered and stored through forest management techniques, such as conservation, regeneration, and afforestation, between the years of 1995 and 2050 (Brown 2002). Tropics have the potential to sequester 80% of the estimated amount, with tropical America accounting for one-third of the tropics or one-fourth of the world's potential. Note that these estimates were made based on physical possibility and socioeconomic factors were not taken into account. These estimates suggest that a shift to more sustainable forest management in tropical America can help to mitigate CO_2 emissions.

2.4 Forests as contributors to rural livelihoods in developing countries. Poor rural people in developing countries rely heavily on forest resources. Forests can provide land for farming, grazing, or hunting, fuelwood, timber, various other non-timber products, as well as conservation of soil and water resources (Arnold 2002). Over grazing, shifting cultivation, and excessive fuelwood gathering contribute to the depletion and disturbance of forests.

As forest resources become scarce, rural inhabitants must move deeper into the forest to provide for their families (Myers 1991, Palo 1996). As this cycle continues, forests disappear, poverty increases and CO_2 is released into the atmosphere.

One example of this cycle is the shifting cultivator, the principle cause of tropical deforestation, which accounted for at least half of all deforestation during the 1980-1990's (Myers 1991). Often due to increased population growth, as well as other factors such as peasant farmer poverty and inequitable distribution of land, the result is farmers pushed out of their traditional farmland. Lacking alternative resources, farmers move to unoccupied forest lands. In Columbia, Peru, Ecuador and Bolivia, slash-and-burn agriculture, which shifting cultivators often use, was the principle manner of deforestation in the 1980-1990's. Notably this vicious cycle is not only due to regional and national socio-economic problems, but also policies of the U.S and other northern countries (Myers 1991, Palo 1996). Focusing on meeting the needs of the poor rural communities and breaking the cycle of forest destruction is one way the Kyoto Protocol and CDM focus on mitigating climate change.

3. Impact of forestry management on the community

3.1 Clean development mechanism. The Clean Development Mechanism (CDM), a component of the Kyoto Protocol, supports joint projects with developing countries to reduce industrialized nations' emissions. The Center for International Forestry Research (CIFOR) describes how the managing forests for carbon sequestration, specifically through CDM projects, can improve local livelihoods. Two case studies, referenced from this CIFOR paper, will be examined for their impact on local communities. In order to mitigate CO_2 emissions, community tree plantations are started in Ecuador and forest preserves are set up in Bolivia.

3.2 Community plantation in Ecuador. The current Gross Domestic Product (GDP) of Ecuador is $37.2 billion U.S. dollars (CIA Factbook 2002). Just for comparison, the GDP of the U.S. is $10.0 trillion U.S.dollars (CIA Factbook 2002). Ecuador not only has the largest population growth rate of South America at 2% per year, but also has the highest population density in South America at 41 people km^{-2} (Allen, 2000). Approximately 13 million people live in Ecuador. Fifty percent of Ecuador's land-use is categorized as forest and woodland. In 1999, 50% of the population was below the poverty level with a 13% unemployment level. These statistics help to explain why slash and burn farming was the major cause of deforestation in Ecuador in the 1980-1990's.

The CDM project in Ecuador was organized by the Forests Absorbing Carbon Dioxide Emission foundation (FACE) and the Ministry of Environment of Ecuador. FACE is a non-profit organization that has been funding the planting and maintenance of forest projects for governments, companies, organizations and private individuals since 1990. Due to land-use issues in Ecuador, FACE organized community tree plantations in higher-altitude Andean regions with farmers and farmer's associations, taking advantage of the otherwise unusable land. As of 2001, 25,000 ha have been replanted.

To start organizing community plantations, an Ecuadorian office (Profafor) has been set up in Quito to accept grant applications from local farmer groups for planting costs and material. Local employees at the Quito office screen applications, supervise and control planting, and deal with administrative needs. As farmers apply for grants, the proposed land is assessed for soil, water and geographic features.

Investing farmers will be able to harvest the trees in 20-30 years. Because of the previous deforestation by the Incas and the Spanish settlers, the land is not viable for farming or livestock grazing. Knowing that they are replanting on otherwise low productive land allows them to shift to planting trees. During this time, farmers are responsible for planting and maintaining the forests. Incentives for the farmers include planting materials and monetary payment during the planting process that may last up to three years. After the planting is completed, yearly monetary support continues. In the case that the forest owner cuts any trees, the owner replants using personal money.

In this case, the inability of government nurseries to provide high quality plant material at the demand level needed, opened up an opportunity for private, local, often beginning growers. It has been found that community groups with many landowners have better success than individual landowners, because the risk is spread out and marginal groups have more involvement opportunities.

3.3 Advantages and disadvantages of community tree plantations. The direct income from planting trees is a definite benefit to the communities and families involved (Table 1). The income may be used to further agroforestry efforts or start microenterprises as suggest by the CIFOR report, but it may also be used to buy the basic needs of food, clothing and fuel.

A second important benefit of community plantations is the use of low-productive land (Table 1). Many rural farmers are locked into their small patches of land and tend to farm it intensively until the productivity declines at which point they convert it into pasture and overgraze until it can no long support grazing. At this point, their options for other sources of income are few. However, community plantations, which help to revitalize the land by decreasing erosion and loss of topsoil, are one option that the farmer can look into and thus use his land more efficiently.

In order for the community plantations to be successful, educational resources and training can be provided to ensure successful management (Table 1). While this is not an essential characteristic of all community plantation projects, it is in the best interest of all parties involved. The education that communities receive to help them manage the tree plantations is a lifelong benefit.

The direct involvement of the community into a larger organization can be a benefit or disadvantage (Table 1). Being part of a larger cooperative organization may assist communities in developing their own organizational resources. However, if the larger organization is too authoritative, the needs and voices of the community may be lost.

Starting a tree plantation is labor intensive, and depending on how each community responds to the need for workers, the work required may be a disadvantage (Table 1). In rural agrarian communities, family roles are clearly defined. If more work is introduced than can be managed through tradition work role division, discord with in the family and community may result. This transition would be the most difficult during the initial labor period, but may resound throughout the whole project.

Community tree plantations have a risk factor (Table 1). Disease, pests, or weather may significantly reduce the size of a plantation and the consequences of circumstantial failure to the communities have not been addressed by the CIFOR report.

Overall, with the perspective of the most basic project in mind, the certainty of income and efficient land-use may out weight the certain disadvantage of intensive labor.

3.4. Conservation case study in Bolivia. The GDP of Bolivia is $20.9 billion U.S. dollars. Bolivia is the least densely populated country in South America with only 7 people km^{-2} (Allen 2000). Today, 8 million people live there with a 1.76% growth rate per year (CIA Factbook 2001). Fifty-three percent of Bolivia's land-use is categorized as wooded or forest (CIA Factbook 2002). With an unemployment rate at 11.4 % in 1997, more recent estimates show that 70% of the population lives below the poverty level (CIA Factbook 2002).

The Noel Kempff Mercado Climate Action Project preserves 4 million acres of tropical forest in northeastern Bolivia that is currently surrounded by timber concessions. A partnership between the Government of Bolivia, Friends of Nature Foundation, The Nature Conservancy and three electric utilities: American Electric, BP Amoco, and PacifiCorp, was made to preserve tropical forest and sequester CO_2 for thirty years.

Unlike the project in Ecuador, this project, the largest of its kind in the world, sequesters carbon through the preservation of the forest. In order to protect the large park, infrastructure and ranger stations have been constructed. In order to become self-sustaining, an ecotourism program and sustainable botanical business were started to offset maintenance costs.

Alternative economic development activities helped to assist local communities. For example, over half of the park rangers were hired from local communities. The project has also established revolving loan funds for microenterprises, such as heart-of-palm plantings, agroforestry projects, animal husbandry and small bakeries. In addition, the project has provided funding to: enhance health care programs with a dedicated physician, provide emergency medical air service, purchase an ambulance and radio system, stock of pharmacies with needed medicines, install potable water supplies and sanitation systems, improve schools, repair roads and bridges, and establish better communication systems. One of the most important activities funded by the project is technical and legal assistance to obtain title to the land on which the indigenous people live (Noel Kempff Mercado Climate Action Project, 2002).

This project, with a very different strategy from FACE's, is helping the rural community by assisting in small business and community development activities in order to shift the communities needs away from forest resources.

3.5 Advantages and disadvantage of forest preservations. There are numerous advantages offered to the communities in this case study (Table 2). The income derived from job opportunities would help to meet their basic needs as well as assist in agroforestry advancements (Table 2). The opportunity to benefit from a business loan and start a small business is a great advantage, whereas before, because of bank restrictions, may have been nearly impossible. Also the assistance for obtaining land tittles is invaluable since the process is long and complicated (Table 2). The benefits of owning a small business or land tittle would last past the preserve's 30-year lifetime, unlike some of the other benefits. While these are very valuable benefits, specific to this preserve project, they are not required components of a reserve project and it is uncertain if these benefits would be extended to other preservation projects managed by other companies.

Benefits to improve the health, sanitation and infrastructural needs of the surrounding communities are key to encouraging local support for the project and would help to ensure smooth transition. However, assisting the local communities is not mandatory to the preservation design and companies on lower budget may decide to reduce the opportunities available to the locals.

The loss of access to land is the only certain disadvantage of the preservation project. Depending on the local communities' use of this land prior to its preservation status, the community might lose fuel, hunting, timber, and agricultural resources.

Overall, with the most basic preserve project in mind and depending on various factors, the certain loss of access to food and fuel sources, may be greater than the benefits that a company or organization decides to provide to the community.

The advantages and disadvantages of forestry practices on local communities may be weighed differently depending on the specific case. The effect of forestry projects on local rural communities and CO_2 mitigation will not be known for several years. However, determining which forestry practices are more beneficial, not only in terms of CO mitigation, but in terms of societal benefits will help prepare a standard of measure for future projects. Plantation forestry projects have certain community benefits required in the structure of the project itself. The community must have an incentive and receive a reward for its investment in the plantation project. Preservation projects seem to necessitate community benefits in order to smooth the land-use transition. However, the type and number of community benefits is decided by the company or organization and are not a mandatory component to producing a forest preserve.

4. Conclusion

Latin American forests have the potential to negate a portion of GHG emissions and decrease the effects of climate change, but are under socioeconomic pressure from rural communities trying to maintain their livelihoods partially based on forest resources. The CDM offers a unique opportunity to alleviate global climate change by focusing on balancing the needs of rural communities with surrounding forests or forestry products. However, the type of forestry project will impact local villages in different ways. Analyzing the social impacts of the forestry project on local communities in conjunction with the economic efficiency to the industry will help to create smoother transition to these forestry practices and greater success for the parties involved.

Table 6. The advanatages and disadvantages of community plantation projects to sequester CO_2 based on a case study in Ecuador.

Characteristic	Advantage/ Disadvantage	Certainty	Duration
Direct Income	Advantage	Very	Project
Use of Low-productive land	Advantage	Very	Project
Land management education	Advantage	Somewhat	Lifetime
Part of larger organization	Advantage Or Disadvantage	Very	Project
Labor/ Time investment	Disadvantage	Very	Large initially then subsides
Risk	Disadvantage	Little	Project

Table 7. The advantages and disadvantages of preservation projects to sequester CO_2 based on a case study in Bolivia.

Characteristic	Advantage/ Disadvantage	Certainty	Duration
Job opportunities	Advantage	Little	Project
Loan opportunities	Advantage	Little	Project
Health assistance	Advantage	Little	Project
Sanitation and infrastructure improvement	Advantage	Little	Beyond project
Land tittle assistance	Advantage	Little	Lifetime
Loss of access to land	Disadvantage	Very	Project

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