# Assessing the effectiveness of reforestation efforts in the tropical montane cloud forest of Costa Rica

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## Abstract

Tropical montane cloud forests are important and unique ecosystems in Costa Rica. However, a large percentage of them have been cleared since the 1950s to make way for agriculture. Cloudbridge Nature Reserve, a privately-owned reforestation project and research station in south-central Costa Rica, is working to return its abandoned pastures back to their natural climax cloud forest state through various reforestation efforts. Because of the costly nature of reforestation, Cloudbridge would greatly benefit from knowing how effective its work has been thus far. To answer this question, tree surveys were conducted at three sites within the Reserve, encompassing a mix of forest cover types: manually planted forest cover and natural regeneration of various ages. Specimens were classified as pioneer or climax species, and the quantities of individuals of each species class found in each type of forest cover were compared. Furthermore, forest stand parameters such as ratio of tree biomass to total biomass, above-ground biomass, and average stand diameter were used to determine and compare successional forest stages of the sites surveyed. Fisher's exact tests and one-way ANOVA were employed to conclude that the reforestation efforts at Cloudbridge are definitely aiding the cloud forest to regenerate more quickly than it would naturally, but it is unclear exactly how much they help.

*Keywords:* tropical montane cloud forest, reforestation, succession, pioneer species, climax species, Costa Rica

Submitted to Cloudbridge Nature Reserve on 10 May 2015.

## 1. Introduction

Across our planet, forests support life in many ways. Nearly 1.6 billion people rely on them for a living, while two-thirds of all terrestrial plants and animals make their homes within the woods (UNEP 2011). Forests also store more than 650 billion tons of carbon, more than can be found in the entire atmosphere (FAO 2010); this is a significant amount considering carbon's damaging climate change potential. These numbers would seem to indicate that it would be in humanity's best interest to preserve and even increase the extent of forests found worldwide, yet recent and historical deforestation statistics show that the opposite is true. Each year, we lose 13 million hectares of forest to various social and environmental forces; agriculture is responsible for the majority of this deforestation (FAO 2010).

Even in Costa Rica, one of the most popular ecotourism destinations in the world, forests haven't always been valued the way they are now. From 1950 to 1990, the country lost 65% of its forest cover, primarily to the cultivation of agricultural products such as bananas, beef, palm oil, coffee, and timber. In the 1960s, the Costa Rican government also initiated a land colonization program that instructed prospective homesteaders to "'improve' virgin 'farm' land" by clearing the property they wanted to claim and work (Evans 1999, 42). Since the policy promoted agricultural colonization above ecological concerns, farmers were encouraged to settle even in steeply sloped mountainous areas, due to Costa Rica's lack of flat land. As a result, the nation lost even more of its unique forests and suffered widespread degradation of its steep mountain terrain (Evans 1999).

Cloudbridge Nature Reserve (CNR) is located in one such place in Costa Rica affected by the deforestation craze. This privately-owned reserve covers 280 hectares (almost 700 acres) of what was once tropical (pre-)montane cloud forest before it was cleared to make way for numerous cattle and small subsistence farming operations starting in the 1950s. Founded in 2002, Cloudbridge functions as a reforestation project and research station, dedicated to creating a biological corridor to link the small remaining patches of primary cloud forest left in the area and to helping the forest return to its natural mature (or climax) state.

These tropical montane cloud forests are unique and important ecosystems. In addition to being biological hotspots, they are "critical […] for water production, sources of medicine, carbon sinks and reservoirs, areas for recreation, landscapes of great scenic beauty, and other environmental services" (Kappelle 2008, 60). However, since they rely on clouds to supply the majority of their moisture, they are vulnerable to climatic changes that alter weather patterns, as has become increasingly common in the past decades. With such environmental changes, each patch of mountainous cloud forest will become more isolated from its neighbors, islands unable to move and adapt that will eventually disappear, unless there are concentrated efforts to restore or expand their range. This danger is very real: negative changes in cloud cover and subsequent ecosystem health have already been noticed in Monteverde, Costa Rica's other main area of montane cloud forest habitat (Foster 2001).

This observation makes the reforestation efforts at Cloudbridge all the more important as a way to restore and reconnect the local cloud forest "islands". However, since reforestation work is costly and time-consuming, Cloudbridge would greatly benefit from knowing how effective its projects have been thus far. This research was designed to examine that question, and to assess the regeneration of the tropical montane cloud forest present within the Reserve.

The easiest way to assess the forest's progress back towards its natural state is to inventory the number and relative proportion of pioneer and climax tree species growing around CNR. As defined by Whitmore (1989), the pioneer class contains species that are able to germinate in full sun and high light conditions (which makes them ideal for recolonizing abandoned farmlands), while the climax class includes species that must germinate under various levels of canopy shade. Climax class species are also much more predominant when the forest has reached its climax state, a natural mature equilibrium that it maintains for hundreds of years. The original forests of the Reserve in their climax state were dominated by oak (*Quercus spp.*) and Mexican elm (*Ulmus mexicana*) trees, so these species are targeted and heavily planted through CNR's reforestation efforts, along with other important local native species. Since restoring Cloudbridge's forests to this natural mature condition is the primary goal of its reforestation work, the success of this goal can be measured by the presence or absence of these climax tree species. Therefore, the main focus of this work is to determine whether or not the manual replanting of trees significantly increases the quantity of individuals of climax tree species found in regenerating forest areas within the Reserve.

## 2. Methods

### *2.1. Study area and organization*

**Figure 1. Location of Cloudbridge Nature Reserve in Costa Rica. Map edited from Wikimedia Commons image.**

Cloudbridge is located in the south-central region of Costa Rica, on the southern slopes of the Talamanca mountain range and adjacent to Chirripó National Park, a UNESCO World Heritage Site. CNR encompasses 280 hectares (almost 700 acres) of tropical (pre-)montane cloud forest habitat, ranging from 1500 m to 2650 m in elevation. Only small portions of its land contain primary cloud forest; the majority is comprised of abandoned or repurposed pastures in various stages of succession returning to the forest's natural climax state.

In order to measure the effectiveness and progress of the reforestation efforts at CNR, it was necessary to sample the trees present in both replanted and naturally regenerating areas, to provide a basis for comparison of the succession of the forest. Three survey sites throughout CNR were chosen, based on the criteria of location, slope, and varying ages. Within each site, three plots were selected to represent the three forest cover types studied: manually planted forest cover (planted), natural regeneration less than 30 years old (nat reg <30), and natural regeneration of 30 years or older (nat reg 30+). In each plot, three transects were established and sampled, each one 10 m long and oriented running directly uphill; in total, then, 27 transects were surveyed.

### *2.2.1. Site descriptions*

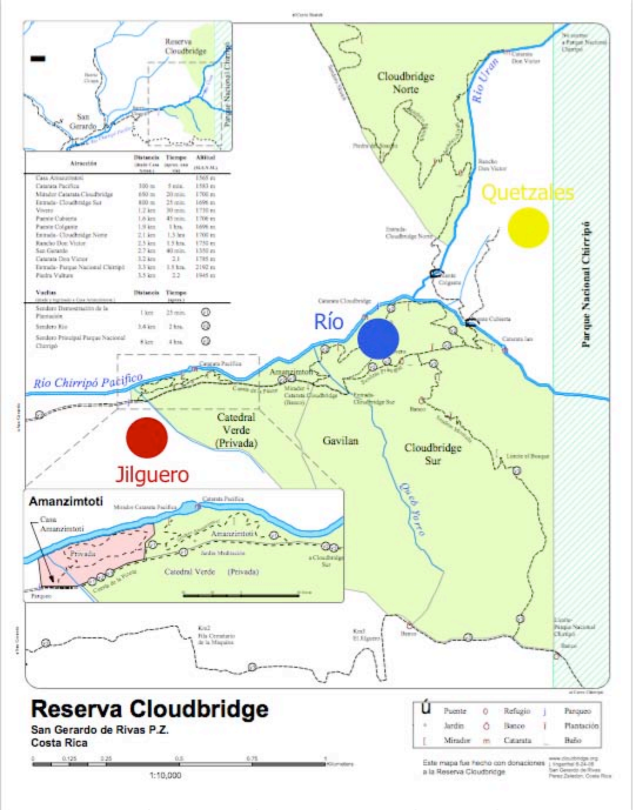


**Figure 2. Three study sites were located throughout Cloudbridge. Map from Cloudbridge archives.**

Jilguero was the youngest of the three sites, with two planted plots of 5 and 8 years and one nat reg <30 plot, also 8 years old. Average elevation for the site was 1613 m, and average slope was 76.2%.

The Río site contained one plot of each forest cover type; the planted and nat reg <30 plots were both 12 years old. The nat reg 30+ plot, 35 years old, was located on the opposite side of Río Chirripó Pacífico from CNR, in the neighboring Talamanca Reserve. Average site elevation was 1628 m and average slope was 21.99%.

The site at Quetzales also included one plot of each forest cover type. The planted and nat reg <30 plots were 7 years old, while the nat reg 30+ plot, located just inside the boundary of Chirripó National Park, was 35 years old. Average site elevation was 1832 m and average slope was 44.62%.

### 2.3. *Field data collection*

Transect surveys were conducted using the methods described by Hessenmöller et al. (2013), applying the "probability proportional to size" theory to a transect sampling approach by recording "all trees growing at a distance less than their height from the transect line" (4). While Hessenmöller et al. employed an upper height limit of 2 m, the upper size limitation for this study was DBH = 30 cm; no lower size limitation was used. These parameters favored sampling of larger tree specimens to better represent the predominant species found in each site, but did not exclude any small seedlings, since in some areas of younger natural regeneration, any climax species found were not likely to be larger than seedling size.

Transect-specific information, such as number, location, plot type, slope, GPS coordinates, special observations, and photos, was recorded for each survey. Individual specimen data was also collected, including height (m), DBH (cm), species if known, photos and samples of unknown species, and the position along the transect for spatial distribution. Once the three transects in a plot had been surveyed, the total area ($m^2$) of the plot was also measured. Using the samples and photos taken from the field surveys, unknown species were identified where possible using various books and websites listed in the References section of this work, and were then classified as either a pioneer or climax species. All data was collected from January to April 2015.

### 2.4. *Two methods of data analysis*

This study utilized two types of statistical tests, designed to analyze distinct aspects of the data. The first method, the Fisher's exact test (significance level $\alpha$=0.05), was employed to determine the significance of the difference in the quantities of pioneer and climax tree specimens found in the three types of forest cover (planted, nat reg <30, and nat reg 30+). Only forest cover types with specimen identification of at least 80% were analyzed, to minimize the uncertainty from excluding a large number of species, present but unidentified, from the data analysis.

The second technique was one-way ANOVA (significance level $\alpha$=0.05), used to test the significance of the classification of successional forest stages done following the procedure established by Lu et al. (2002) in the Brazilian Amazon. Lu et al. developed models for several forest stand parameters able to distinguish between four successional stages of secondary forest, based on DBH and height measurements of trees within the forest. The successional stages ranged from SS1, generally representing very young growth composed mainly of seedlings and saplings, to SS4, very close to being considered mature forest. This method was chosen because it was able to compare the data between all three forest cover types without relying on specimen identification percentages, as it used the other statistics (height and DBH) that were collected for every specimen regardless of identification.

Using this second data analysis approach required the calculation of some of Lu et al.'s forest stand parameters. First, the above-ground biomass of each individual tree (DBH of 10+ cm) or sapling (DBH < 10 cm) was calculated using one of three models. For specimens with a DBH < 25 cm, formula (1) was used:

$$\ln(DW1) = -2.5202 + (2.1400 \times \ln D) + (0.4644 \times \ln H) \tag{1}$$

where $D$ = DBH (cm), $H$ = height (m), and DW1 = biomass (kg) when DBH < 25 cm. For specimens with a DBH of 25+ cm, formula (2) was employed:

$$\ln(DW2) = -3.843 + (1.035 \times \ln(D^2 \times H)) \quad (2)$$

where DW2 = tree biomass (kg) when DBH is 25+ cm. Additionally, Nelson et al. (1999) developed a third formula to calculate the biomass of lightweight pioneer species whose biomass might have been considerably overestimated by the previous models. Therefore, for any specimens identified as either *Cecropia obtusifolia* or *Heliocarpus americanus*, two common hollow or lightweight pioneer species, formula (3) was used to calculate biomass:

$$\ln(DW3) = -2.5118 + (2.4257 \times \ln D) \quad (3)$$

where DW3 = tree biomass (kg) for the two species stated. It is important to note that while the individual biomass of these pioneer species was calculated using a different formula from the two tree sizes above, moving forward into forest stand parameters for each plot they were included in the data of the relevant tree size and not treated as a separate category.

Once individual specimen biomass was calculated, two forest stand parameters could then be found for each plot: ratio of tree biomass to total biomass (RTB) and above-ground biomass (AGB). RTB, the best parameter for distinguishing between all four successional stages, was calculated using formula (4):

$$\mathrm{RTB} = \frac{\textit{tree biomass}}{\textit{total biomass}} \quad (4)$$

where "tree" is defined as any specimen with a DBH of 10+ cm. AGB (in kg/m$^2$), a useful parameter for classifying forest from SS2-SS4, was found using formula (5):

$$\mathrm{AGB} = \frac{\sum_{i=1}^{m} DW1_i + \sum_{j=1}^{n} DW2_j}{PA} \quad (5)$$

where $m$ is the total specimen number when DBH < 25 cm, $n$ the total specimen number when DBH is 25+ cm, and $PA$ the area (m$^2$) of a plot. A third forest stand parameter, average stand diameter (ASD, in cm), is useful for determining stages SS1 and SS2, so it was also calculated by formula (6):

$$\mathrm{ASD} = \sqrt{\frac{\sum_{i=1}^{m+n} D^2}{m+n}} \quad (6)$$

## 3. Results

### 3.1. Comparing the quantities of pioneer and climax tree specimens

Table 1 shows a consolidation of the specimen data from each transect, as well as which type of forest cover each plot represented. This information was further compiled into a contingency table and then graphed (Fig. 3) and analyzed.

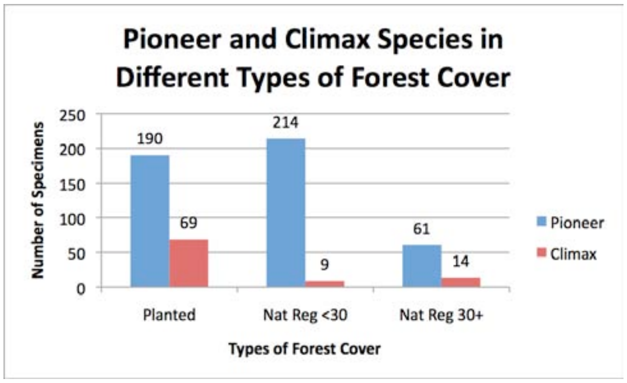


**Figure 3. Pioneer and climax species in different types of forest cover.**

**Table 1. Numbers of specimens sampled and classified.**

| **Site** | **Forest Cover** | **Transect** | **Number of specimens in each species class** | | | | **Total** |
|---|---|---|---|---|---|---|---|
| | | | Pioneer | Climax | Unidentified | Introduced | **Specimens** |
| **Jilguero** | | | | | | | |
| | Planted | JLPT1 | 22 | 14 | 3 | 4 | 43 |
| | Planted | JLPT2 | 14 | 9 | 0 | 0 | 23 |
| | Planted | JLPT3 | 16 | 12 | 2 | 0 | 30 |
| | | *Plot Totals* | *52* | *35* | *5* | *4* | *96* |
| | Nat Reg <30 | JNRT1 | 18 | 2 | 1 | 0 | 21 |
| | Nat Reg <30 | JNRT2 | 22 | 3 | 2 | 0 | 27 |
| | Nat Reg <30 | JNRT3 | 32 | 0 | 8 | 0 | 40 |
| | | *Plot Totals* | *72* | *5* | *11* | *0* | *88* |
| | Planted | JUPT1 | 23 | 8 | 3 | 0 | 34 |
| | Planted | JUPT2 | 12 | 2 | 2 | 0 | 16 |
| | Planted | JUPT3 | 10 | 2 | 4 | 0 | 16 |
| | | *Plot Totals* | *45* | *12* | *9* | *0* | *66* |
| **Site Totals** | | | **169** | **52** | **25** | **4** | **250** |
| **Río** | | | | | | | |
| | Planted | RPT1 | 19 | 1 | 7 | 0 | 27 |
| | Planted | RPT2 | 28 | 0 | 1 | 0 | 29 |
| | Planted | RPT3 | 18 | 2 | 3 | 0 | 23 |
| | | *Plot Totals* | *65* | *3* | *11* | *0* | *79* |
| | Nat Reg <30 | RNRT1 | 19 | 0 | 2 | 0 | 21 |
| | Nat Reg <30 | RNRT2 | 19 | 0 | 3 | 0 | 22 |
| | Nat Reg <30 | RNRT3 | 8 | 0 | 0 | 0 | 8 |
| | | *Plot Totals* | *46* | *0* | *5* | *0* | *51* |
| | Nat Reg 30+ | TRT1 | 11 | 6 | 12 | 0 | 29 |
| | Nat Reg 30+ | TRT2 | 6 | 4 | 15 | 0 | 25 |
| | Nat Reg 30+ | TRT3 | 7 | 3 | 18 | 0 | 28 |
| | | *Plot Totals* | *24* | *13* | *45* | *0* | *82* |
| **Site Totals** | | | **135** | **16** | **61** | **0** | **212** |
| **Quetzales** | | | | | | | |
| | Planted | QPT1 | 10 | 6 | 0 | 0 | 16 |
| | Planted | QPT2 | 13 | 7 | 0 | 0 | 20 |
| | Planted | QPT3 | 5 | 6 | 0 | 0 | 11 |
| | | *Plot Totals* | *28* | *19* | *0* | *0* | *47* |
| | Nat Reg <30 | QNRT1 | 22 | 0 | 2 | 0 | 24 |
| | Nat Reg <30 | QNRT2 | 34 | 0 | 2 | 0 | 36 |
| | Nat Reg <30 | QNRT3 | 40 | 4 | 2 | 0 | 46 |
| | | *Plot Totals* | *96* | *4* | *6* | *0* | *106* |
| | Nat Reg 30+ | CNPT1 | 16 | 1 | 4 | 0 | 21 |
| | Nat Reg 30+ | CNPT2 | 16 | 0 | 2 | 0 | 18 |
| | Nat Reg 30+ | CNPT3 | 5 | 0 | 4 | 0 | 9 |
| | | *Plot Totals* | *37* | *1* | *10* | *0* | *48* |
| **Site Totals** | | | **161** | **24** | **16** | **0** | **201** |
| **Study Totals** | | | **465** | **92** | **102** | **4** | **663** |
| | | | Pioneer | Climax | Unidentified | Introduced | Total |

Although Figure 3 shows the data for both ages of natural regeneration, both were not used for data analysis. From the numbers in Table 1, the percentages of specimens identified for each forest cover type were calculated; planted plots were identified to 91.32%, nat reg <30 plots to 91.02%, and nat reg 30+ plots to only 57.69%. Even if the two ages of nat reg plots were combined, identification only reached 79.47%. Due to the previously established threshold of 80% identification, analysis could only continue for planted plots vs nat reg <30 plots, excluding the data from the areas of older natural regeneration.

Using the Fisher's exact test to compare the difference between these two forest cover types, a p-value of $p=0.00000995362$ was obtained. Since this result was below the significance level of $\alpha=0.05$, it was statistically significant.

### *3.2. Classifying successional stages*

Table 2 shows the final statistics for each of the forest stand parameters discussed in Section 2.4. Comparing these numbers with the successional stage classification chart developed by Lu et al., no apparent patterns emerged, and the results were somewhat contradictory between the different parameters. The one-way ANOVA tests used to analyze these numbers returned high p-values (for RTB: $p=0.6$; ABG: $p=0.767$; ASD: $p=0.978$). Since none of these p-values fell below the significance level $\alpha=0.05$, these results were not statistically significant.

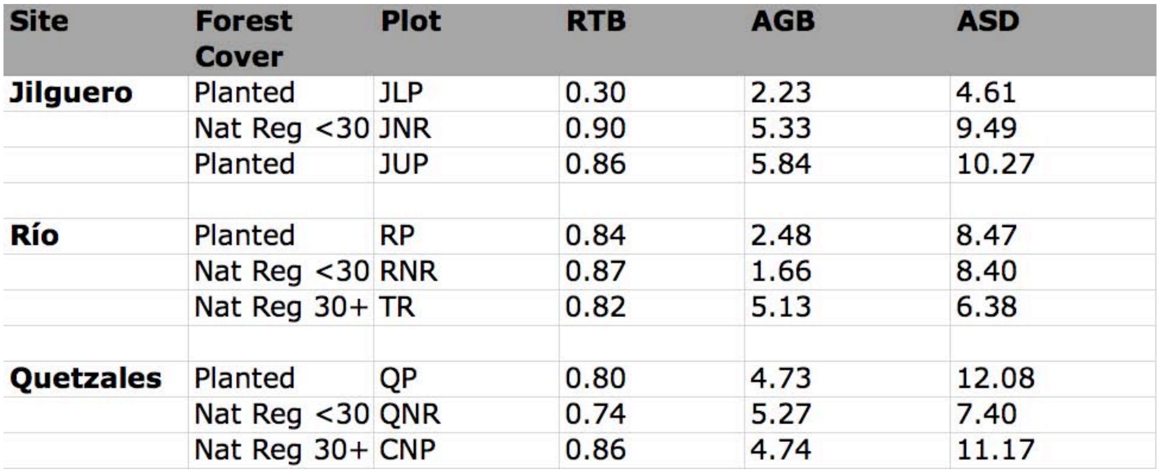
## 4. Discussion & Conclusions

The results of the two data analysis methods used in this study indicate that planting trees definitely aids in forest regeneration, based on the significantly higher numbers of climax class specimens found in planted areas, but it is unclear just how much it helps, since the results of the successional stage tests were inconclusive. The first conclusion is supported by the observation that the two most important climax tree species for Cloudbridge, the oak (*Quercus spp.*) and Mexican elm (*Ulmus mexicana*), were not found growing anywhere that they had not been planted. This is a clear indication that CNR's reforestation efforts are helping those crucial species regenerate much faster than they would naturally.

There were several limitations to this research that leave room for further study. Firstly, identifying tree species in Costa Rican cloud forests is notoriously difficult, and it hindered this research by forcing the exclusion of the 30+-year-old natural regeneration data from the Fisher's exact test. High species diversity, lack of fruits and/or flowers, presence of trees too tall to obtain samples from, and limited species information availability were some of the issues encountered when identifying unknown species. Given more time, more species could certainly be identified.

Secondly, the type of data collected may have biased the successional stages analysis. The formulas used to calculate the forest stand parameters were developed from a study employing a plot survey technique, as opposed

**Table 2. Forest stand parameters used to classify successional forest stages.**



| Site | Forest Cover | Plot | RTB | AGB | ASD |
|---|---|---|---|---|---|
| **Jilguero** | Planted | JLP | 0.30 | 2.23 | 4.61 |
| | Nat Reg <30 | JNR | 0.90 | 5.33 | 9.49 |
| | Planted | JUP | 0.86 | 5.84 | 10.27 |
| | | | | | |
| **Río** | Planted | RP | 0.84 | 2.48 | 8.47 |
| | Nat Reg <30 | RNR | 0.87 | 1.66 | 8.40 |
| | Nat Reg 30+ | TR | 0.82 | 5.13 | 6.38 |
| | | | | | |
| **Quetzales** | Planted | QP | 0.80 | 4.73 | 12.08 |
| | Nat Reg <30 | QNR | 0.74 | 5.27 | 7.40 |
| | Nat Reg 30+ | CNP | 0.86 | 4.74 | 11.17 |

to the modified transect approach used here. The specific data recorded and the survey methods for this study were chosen to give greater importance to the bigger specimens dominant in each site and resulted in an increased count of larger trees and a decreased count of smaller saplings than would be expected from a plot survey. This may have skewed the biomass data by including a higher proportion of large (heavy) trees than normal. The only way to be sure of this is to redo this study following a standard plot approach and compare the results.

A final opportunity for further work is to use this research as the baseline for an ongoing study, in order to track the progress of the forests of Cloudbridge through their years of growth. CNR is still just in its beginning stages of regeneration, so in the future changes will be observed and recording these changes would be beneficial for the Reserve and for other cloud forest reforestation efforts.

Overall, the reforestation work done at Cloudbridge is already showing its benefits, and this is encouraging. Such work should be continued and expanded in order to help Costa Rica's unique tropical montane cloud forest recover and thrive.

## Acknowledgements

I would like to thank Tom Gode, Linda Moskalyk, and Siân Clarke for all their help and support throughout this research. I'd also like to thank Cloudbridge Nature Reserve and Talamanca Reserve for the opportunity to study their beautiful forests.

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