Using Aerial Imagery to Assessing Tropical Forest Cover Surrounding Restoration Sites in Costa Rica

by

Jorge Amar

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To my mother,
who has given us her all,
and inspires us to do the same.

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List of Abbreviations

AOI	Area of Interest
ASL	Above Sea Level
DEM	Digital Elevation Model
GIS	Geographic information system
LCBS	Las Cruces Biological Station
LiDAR	Light Detection and Range
UAV	Unmanned Aerial Vehicle

Abstract

Tropical landscapes in Costa Rica have increasingly become targets of restoration efforts after deforestation depleted 90% of the region's forests by the end of the 20th century. Research has shown that the environment surrounding a restoration site influences outcomes in fragmented landscapes, particularly as to the amount of forest cover surrounding restoration areas. However, the degree of influence that forest cover has on restoration sites and the long-term effects have historically been understudied due to the difficulty in assessing forest cover in remote regions through conventional field methods. As a result, there is a need for more time and cost-effective ways of evaluating and understanding forest cover change within the context of restoration efforts in remote areas.

Geographic Information Systems (GIS) and remote sensing technologies have been utilized by researchers to understand better the relationships between abiotic and biotic factors in ecosystems. This study analyzed forest cover changes from 2005 to 2014 using high-resolution remote imagery to understand how forest cover changed surrounding 13 restoration sites near Las Cruces Biological Station (LCBS). The forest cover analysis revealed that the study region experienced a 9% net increase in forest cover over nine years. Similarly, all except one of the restoration sites had a net increase in forest cover within 200 meters. Topographic variables were extracted from a 5-meter DEM to understand their influence on the changes in forest cover. We hypothesized that elevation, slope, aspect, and distance to restoration site would have a strong and positive correlation with whether areas surrounding the restoration sites reforested from 2005 to 2014. A regression analysis revealed that topographic factors do not solely explain the variations in forest cover gain between sites; However, aspect, elevation, and distance to the restoration sites center had a significant impact on forest cover gain in the study sites.

Chapter 1 Introduction

Tropical forests are the most biologically diverse ecosystems on Earth and provide vital ecosystem services, such as carbon sequestration and water filtration (Busch and Ferretti-Gallon 2017). Deforestation in tropical regions mostly results from anthropogenic land-use changes such as agriculture and logging (Gibson et al. 2011). Decades of research demonstrate how the perverse degradation of landscapes has resulted in changes in the global carbon cycle and loss in biodiversity (Vitousek et al. 1997; Foley et al. 2005). As a result, tropical landscapes have increasingly become targets of restoration efforts worldwide due to the adverse effects observed from deforestation, agriculture, and fragmentation, to name a few (Sader and Joyce 1988; Holl and Kappelle 1999).

Ecological restoration is the science of rehabilitating degraded habitats to a semblance of their historical state, restoring ecosystem services, and improving biodiversity (Bell et al. 1997). Restoration ecology is complex and interdisciplinary – drawing on concepts from landscape ecology, biology, geography, and geology. Some of the research in the rehabilitation of tropical forests focuses on improving the methodologies behind active restoration practices, but studies are often limited in scope and quantity (Bell et al. 1997; de Souza et al. 2013).

Geographic Information Systems (GIS) have been employed in landscape-level studies to assess forest cover changes relating to ecological restoration efforts. Research in restoration ecology has benefitted from GIS by allowing users to better understand landscape-level elements and their impact on restoration outcomes. Research studies have also demonstrated instances where the restoration's success is conditional to the landscape context, specifically variables such as habitat connectivity, the amount of surrounding forest cover, and the degree of fragmentation (Bell et al. 1997; Naveh 1994; de Souza et al. 2013). As a result, it is critical to understand the influence of surrounding forest cover in ecology, so practitioners can better implement effective restoration strategies that consider how the surrounding environment is contributing to the success of active restoration efforts (de Souza et al. 2013).

A large-scale tropical forest restoration project was established in 2005 at Las Cruces Biological Station (LCBS) in Costa Rica. The study aimed sought to understand the efficacy of different tree-planting strategies in tropical regions. Since there is good evidence that the outcomes of restoration efforts depend largely on the landscape context – such as the positive influence of high habitat cover on restoration effectiveness – this study will supplement the ongoing research in Costa Rica by quantifying the surrounding forest cover near 13 restoration sites. By providing baseline data on forest cover changes since the start of the project, future research can evaluate restoration success against the landscape context presented in this study. Additionally, this study will investigate the effect that elevation, slope, aspect, and distance to the site's center have on forest cover gain surrounding the research sites between 2005 and 2014 periods using regression analysis.

1.1. Tropical Forests – A History in Costa Rica

Tropical forests are the most biodiverse region on Earth. They are regarded for their essential roles as terrestrial carbon sinks, sequestering carbon dioxide from the atmosphere, and storing it in the vegetation and soil (Pan et al. 2011). Tropical forests once covered 96 to 99% of the land in Costa Rica, but after an increase in agriculture and pasture grazing, deforestation rates skyrocketed in the late 20th century (Leopold et al. 2000; Keenan et al. 2015). It is estimated that 90% of the original forests were lost during this period. Following the destruction of the timber-producing forests, farmers were left with no choice but to abandon their now nutrient-poor pastures (Leopold et al. 2001). However, forest cover in Costa Rica had increased from 2,564-

kilo hectares in 1990 to 2756 kilo hectares in 2015, owing largely to local and international initiatives to reforest cleared areas (Algeet-Abarquero et al. 2015). Additionally, reforestation rates were higher than deforestation rates between 1990 and 2015 (Algeet-Abarquero et al. 2015; Keenen et al. 2015). As a result, many conservation efforts in the tropics aim to foster the recovery of secondary forests through restoration practices.

Tropical forests are defined as closed-canopy forests that exist between 28 degrees north and south of the equator and are regarded highly for their abundant levels of biomass and biodiversity (Park 2002). Secondary forests in the tropics mainly result from human impacts such as the abandonment of cleared forest lands, typically areas previously used for agriculture (Brown and Lugo 1990). In contrast, primary forests are forests with no visible evidence of human disturbance and now comprise a smaller area of the tropics. However, the regeneration of old-growth forests is not possible (Chazdon 2017). As a result, much attention has shifted towards the recovery and maintenance of secondary forests, as they now comprise more than half of the tropical forests worldwide (Chazdon 2016).

Due to their significance in the global carbon cycle, much attention has been placed on the recovery of aboveground biomass in tropical regions. The fostering of secondary forests is corroborated by studies that have shown the resiliency and productivity in tropical secondary forests (Poorter et al. 2016). However, the natural regeneration of tropical forest systems is impeded by low seed dispersal, predation, poor seed germination, and low survival rates of seedlings (Holl et al. 2001), calling for active restoration strategies that accelerate the natural recovery process.

Initiatives to combat climate changes through tropical forests restoration have enacted international policies such as the Reduced Emissions from Deforestation and Land Degradation

(REDD+), which incentivizes the reforestation through the monetization of ecosystem services, such as payment for carbon sequestration (Daniels et al. 2010). In 1996, Costa Rica instituted a Payment for Environmental Services (PES) program called Pago por Servicios Ambientales to incentivize and compensate landowners for providing ecosystem services through their forested lands (Daniels et al. 2010). As a result, reforestation efforts have grown tremendously due to policies enacted by growing environmental degradation concerns.

Consequently, there has been an increasing need for viable restoration strategies that accelerate the rate of recovery in areas that were previously used for pasture regions into more productive landscapes. Additionally, since most of the tropical forests are now comprised of regenerating forests, there is a need for understanding the underlying elements influencing the restoration outcomes, particularly in abandoned pastures (Chazdon 2017). Accordingly, restoration research in Costa Rica focuses on gaining a comprehensive understanding of tropical ecosystems to implement more efficient restoration strategies.

1.2. Study Area

1.2.1. Site Description

The study will examine data collected near Las Cruces Biological Station, which is in southern Costa Rica (Figure 1; (LCBT; 8˚47' 7" N; 82˚57' 32" W). The ~ 326-hectare (ha) reserve was once an area primarily used for agriculture and grazing before its acquisition in 1962 by the Organization of Tropical Studies (OTP) and repurposed for botany, conservation, reforestation research (Holl et al. 2017). The reserve also serves other functions, such as for research and education about tropical systems and a tourist destination.

The region still maintains remnant fragments of old-growth forest (~200 ha) with no history of logging, burning, agriculture, or other disturbances. Approximately 50 ha are composed of secondary forests, which are forests that have regrown from disturbances from a long enough time to where the effects of logging, fire, grazing, or agriculture are no longer apparent. The region is classified as a tropical premontane forest, existing at an elevation range of 1100-1430 meters above sea level (asl) and averages 4 meters (~157 inches) of rainfall annually.

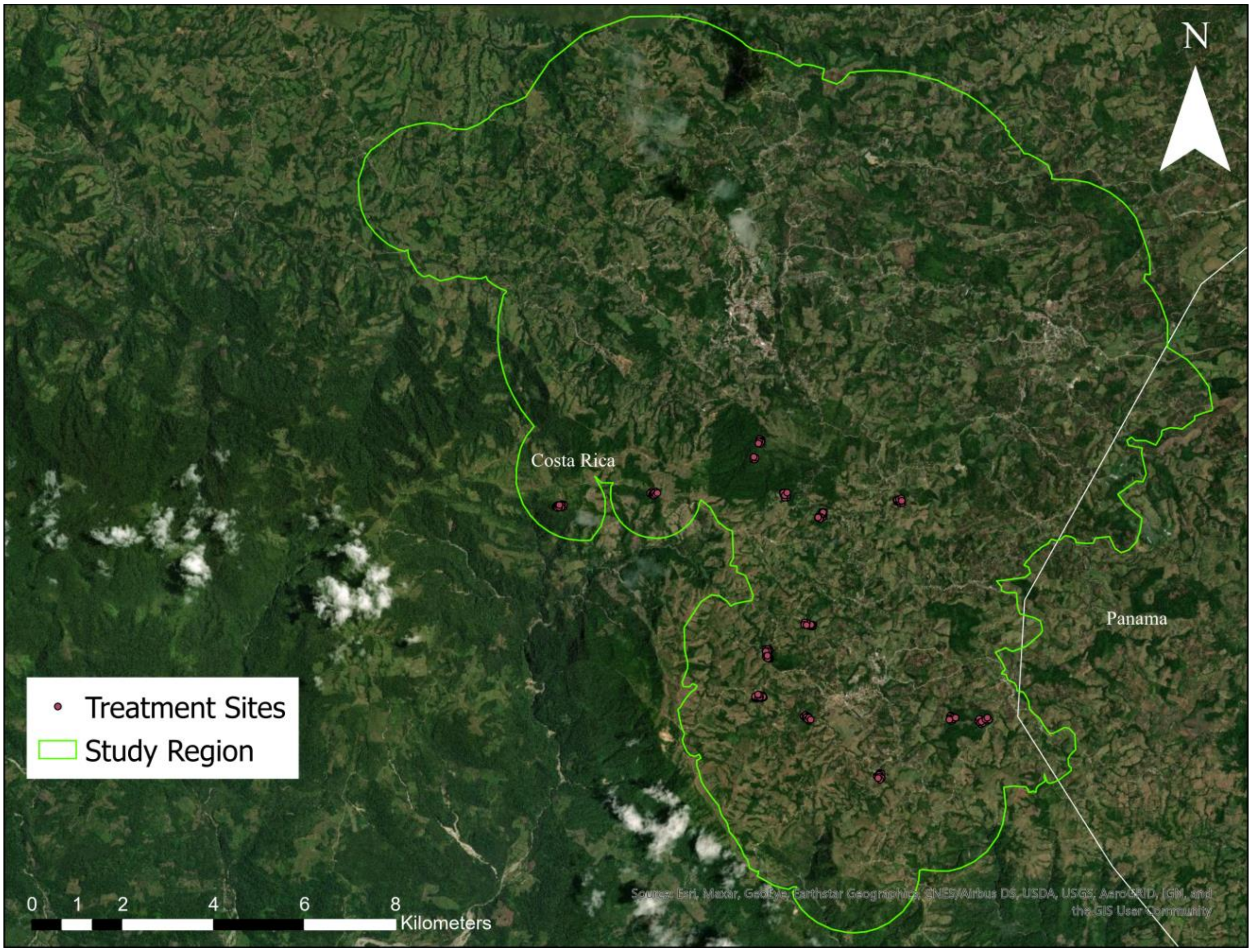

Figure 1 Study area surrounding the 13 restoration sites at Las Cruces Biological station. There are 39 treatments and three treatments at each site.

1.2.2. Restoration Sites

A total of 13 restoration sites were established near Las Cruces Biological Station in southern Costa Rica between 2004 and 2005 (Zahawi et al. 2013) to understand the efficacy of three restoration planting strategies in a tropical premontane rain forest zone (Holdridge et al.

1971; Holl et al. 2011). LCBS is a highly fragmented landscape of forest patches and areas previously used for various types of agriculture (Zahawi et al. 2013). Specifically, the sites were chosen by Zahawi and colleagues (2013) and consist of abandoned pastures that were once used for agriculture for over 18 years. The sites were cleared and burned before the start of the study, but not after. Before clearing, the sites were dominated by exotic, or non-native, grass species (Zahawi et al. 2013).

The ongoing study in the LCBS seeks to determine the efficacy and long-term effects of these three planting styles to determine which are better suited for tropical forest restoration (Zahawi et al. 2013). The treatments are 50 x 50 meters and are a minimum of 5 meters apart from each other. Elevation ranges from 1,060 to 1430 meters above sea level. The thirteen sites are separated by a minimum, and a maximum distance of 0.7 and 8 kilometers, respectively, and have different measures of slope ranging between 5-35 degrees. The aspect ranges between each site as well (Zahawi et al. 2013). Additionally, the sites are spread over regions with varying surrounding forest cover. The varying topographic profiles of each site allow us to compare the relative importance of topography in forest cover gain over time.

1.2.3. Planting Styles

The goal of assessing different planting strategies is essential when attempting to accelerate and influence the rate of recovery through active restoration practices. Each restoration site consists of three treatments, which include plantation, nucleation, and natural regeneration (Figure 2). Plantation restoration treatments are designed to cover the entire target region, rows of varying plant styles. As a result, plantation strategies are more expensive to implement and can result in homogenous landscapes (Holl et al. 2011; Zahawit et al. 2013).

Nucleation, or island, treatments refer to planting done in separate clusters rather than rows. Research suggests that the nucleation model strongly mirrors the natural succession of forests. As a result, studies have looked at applying nucleation treatments rather than plantation or natural regeneration. Additionally, previous studies show that nucleation treatments (Figure 2) were associated with higher restoration success, having higher seedling survivability and species density. However, the effect that nucleation treatments have on the surrounding landscape cover has not been extensively studied. Opting for island-style treatments have garnered attention in restoration ecology because it is more cost-effective, especially when rehabilitating larger landscapes (Lindell et al. 2012) since they require fewer plantings than plantation-style treatments.

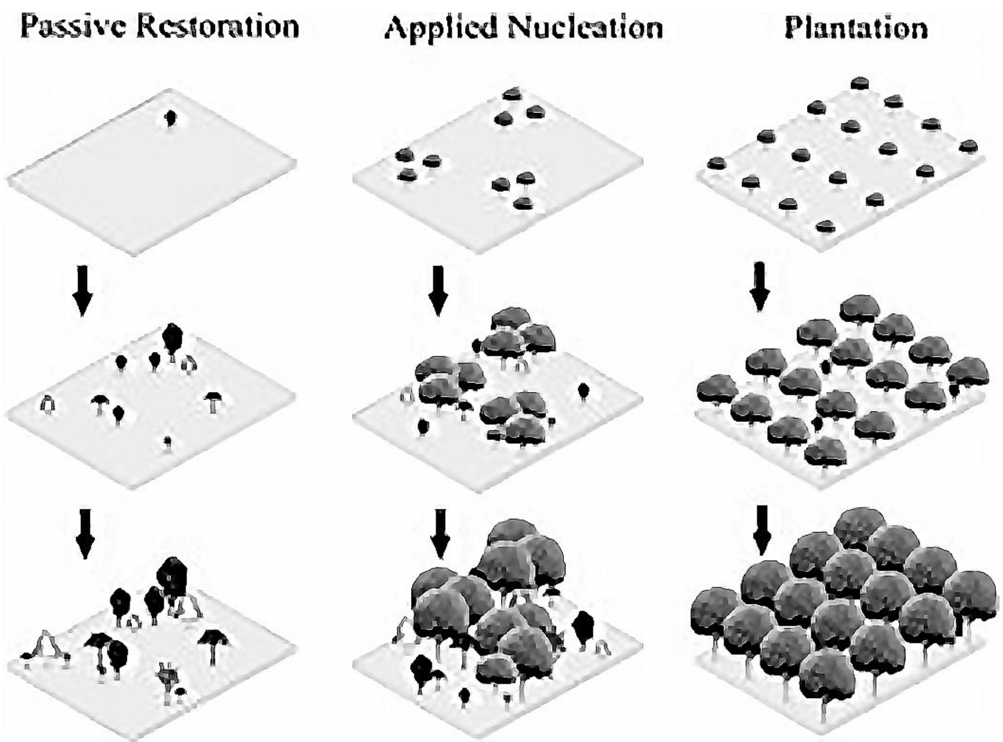

Figure 2. The observed outcomes of the three planting strategies. Passive restoration outcomes vary. Applied nucleation, or island treatments, result in more heterogeneous cover. Plantation style treatments can result in monocultures with the outcome varying greatly from natural succession outcomes. Source Holl et al. 2011

Natural regeneration has variable outcomes and, in some cases, without interference, regions left to recover naturally remain in a suspended state dominated by woody vegetation (Figure 2; Holl et al. 2011). The restoration study sought to evaluate the efficacy of these planting strategies in a tropical landscape.

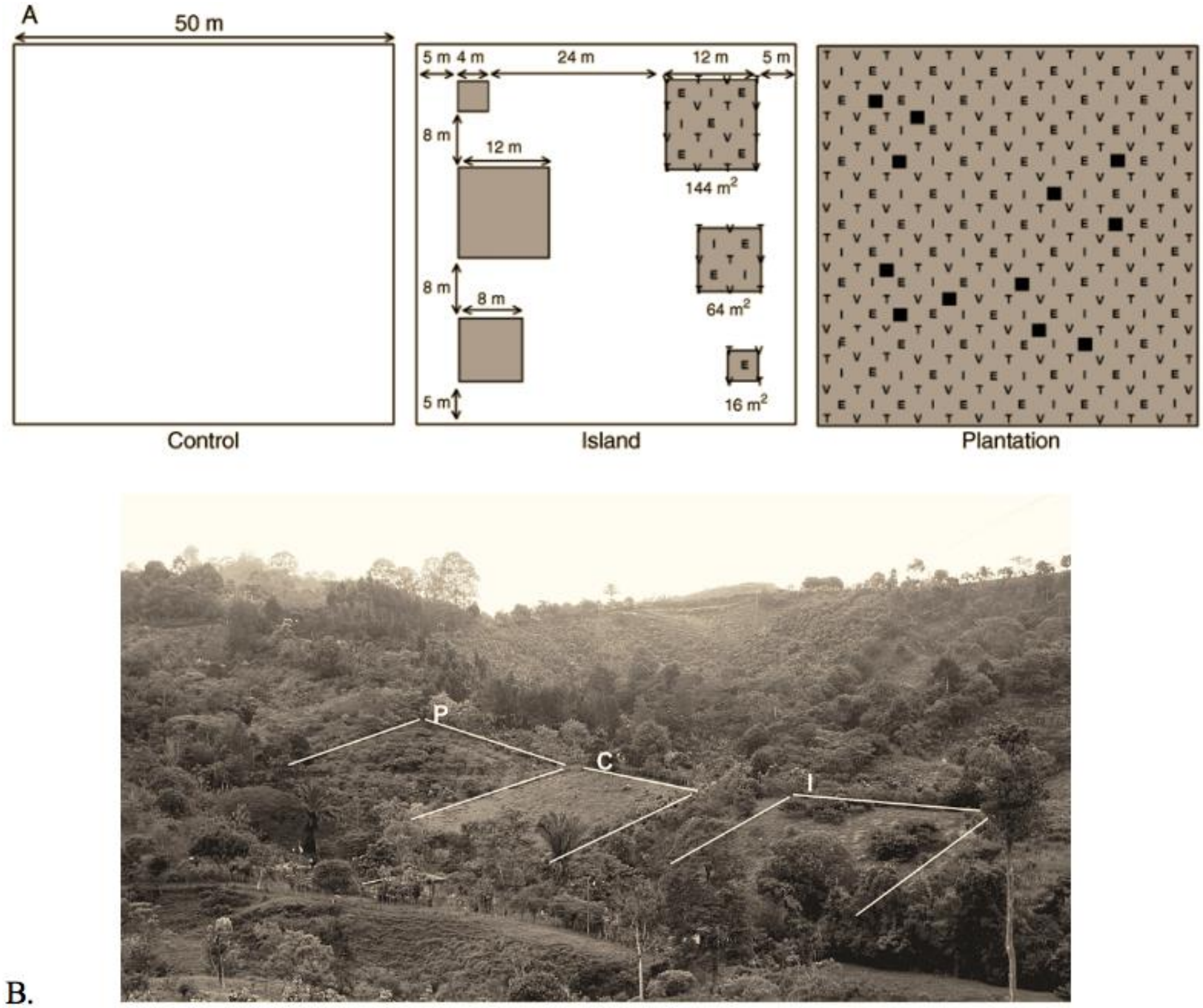

Figure 3 (A)Experimental design of each treatment plot. Treatments are a minimum of 5-meters apart and were randomized. Capitalized letters within island and plantation plots represent tree species seedlings (T = *Terminalia amazonia*, V = *Vochysia guatemalensis*, E = *Erythrina poeppigiana*, I = *Inga edulis*). Black squares in the plantation treatment represent locations of seed traps that were used in a previous study. (B) Photo of the experimental design. Images were taken from Cole, Holl, and Zahawi 2010.

1.3. Current Research

The initial study by Zahawi et al. 2013 investigated the potential of three different planting styles for active restoration practices and found that the island strategy was a viable option for returning heterogeneity and closely match the outcomes of natural succession. However, they explain that continued monitoring should be conducted to understand the long-term effects and outcomes better.

Since the establishment of the restoration project near LCBS, additional studies have investigated the long-term effects that different tree-planting styles had on seed recruitment (Holl et al. 2017), seed establishment (Reid, Holl, and Zahawi 2015), and bird recruitment (Reid et al. 2014). Additionally, Holl et al. 2017 assessed the effects that the surrounding forest cover had on seed recruitment within the three treatments, and they found that forest cover did not have a strong correlation with the establishment of trees or the amount of seed rain found at each site. However, no studies have evaluated how the surrounding forest cover surrounding the restoration project in Costa Rica has changed between 2005 and 2014.

1.4. Objective

The goals of this study are to (1) quantify and compare the changes in tropical forest cover between 2005 and 2014 surrounding thirteen restoration sites in southern Costa Rica using hand-digitized aerial imagery; (2) compare the overall changes between 2005 to 2014 in forest cover density for the entire study region; (3) assess the relationship between forest cover gain, distance from the center of the site, elevation, slope, and aspect using regression analysis.

1.5. Thesis Organization

The following section will provide information supporting the importance of understanding and incorporating the landscape-level processes and the effects they have on restoration outcomes. Information on the type of remote sensing technology used in this study will also be discussed. Chapter 3 outlines the process used to complete this project, such as data collection, processing, and analysis. Chapter 4 presents the results of the analysis. Chapter 5 discusses the findings, implications, and ways to improve future studies.

Chapter 2 Background and Literature Review

This chapter reviews literature highlighting the influence of surrounding habitat cover in the context of restoration ecology. The goal of this chapter is to provide background information on landscape ecology as it relates to restoration studies and the methodologies used for quantifying forest cover. This study aims to supplement the restoration work that is ongoing in these field sites in Costa Rica and understanding how the surrounding landscape has changed from the start of the project. The following literature has demonstrated the different uses of GIS and aerial imagery to quantify forest cover and the connection to restoration ecology. This chapter presents background information on the importance of landscape-level factors in restoration ecology, aerial imagery to classy forest cover, and other studies that pertain to the thesis objective.

2.1. Understanding Landscape-Level Processes in Restoration Ecology

2.1.1. Restoration Ecology

Restoration ecology is the discipline involving the recovery of degraded, damaged, or destroyed ecosystems (Aronson 2005). Historically, conservation efforts have focused on preserving areas with little disturbance; however, efforts have now shifted towards the active and passive restoration of degraded ecosystems due to extensive anthropogenic land cover changes (Holl and Aide 2011). In landscapes that have been degraded due to agriculture production, ecological restoration attempts to improve the functionality of the land and return a semblance of the former ecosystem. More importantly, active restoration practices enhance biodiversity and ecosystem services at the landscape level (Aronson 2005).

Tropical regions are primarily known for their biodiversity hotspots and richness of endemic species that are not found elsewhere (Mittermeier et al. 1998). However, biodiversity hotspots are often found in developing countries, like Costa Rica, where the restoration of degraded ecosystems are seldom supported without evident socio-economic advantages (Aronson 2005). Some ecosystems in the tropics recover rapidly on their own, while others require humans to facilitate the restoration process actively. As a result, it is the responsibility of land managers to make informed decisions on whether to take an active or passive approach, all the while considering factors such as land-use history, surrounding landscape density, and the natural ecosystem resiliency (Holl and Aide 2011).

Restoration practices vary by degree of human interference but can mostly be classified as active or passive restoration. Active restoration practices involve practitioners in implementing management techniques, such as planting seeds and removing competition of non-native species. Passive restoration involves no interference except for the removal of the disturbance, such as logging or grazing (Rakan, Reid, and Holl 2014). Frequently employed active restoration practices in tropical forest recovery include plantation and island reforestation (Holl et al. 2011). Plantation forestry involves the planting of monocultures, usual rows of a fast-growing species, to kickstart the succession towards native forests. Island forestry is the planting of trees in patches, rather than rows, which is less costly and time-consuming than the latter (Holl et al. 2011).

2.1.2. Landscape Ecology

Landscape ecology studies how spatial processes interact with the abiotic and biotic components of an ecosystem. Advances in remote sensing, geographic information systems, and aerial imagery allow landscape ecologists to understand better the effect of spatial heterogeneity, which is the different distribution of species in an area and the effect on ecosystem processes (Brudvig 2009, 2011).

Understanding the spatial relationship between landscape and restoration ecology is essential for practitioners to develop optimal strategies to rehabilitate and restore degraded habitats, as various studies have shown the influence that landscape-level processes have on restoration outcomes (Bell et al. 1997; de Souza 2013). Landscape-level processes refer to the composition (density) and configuration (connectivity and heterogeneity) of a landscape (de Souza et al. 2013). Instead of solely focusing on elements such as planting style (island, plantation) and the plant species used, future studies can also consider surrounding landscape cover, elevation, and aspect and how they affect restoration outcomes. Large-scale restoration projects in remote regions often utilize different remote sensing and GIS technologies to quantify and assess changes in forest cover, since field measurements at this scope are impractical, time-consuming, and expensive (Chen et al. 1998; Boutin and Hebert 2002; Ruiz-Jaen 2005).

Motivations to track changes in forest cover, particularly relating to restoration ecology, arise from the literature supporting the positive influence of surrounding landscape cover and the increasing need to optimize restoration efforts in degraded lands. For example, De Souza et al. (2013) conducted a metanalysis on restoration projects found that very few studies (54 total) within the past fifteen years had utilized a landscape approach, the majority of which had occurred in the most recent years (2009-2011). Landscape approaches refer to studies that incorporated habitat cover, connectivity, and isolation variables in their investigations. In these studies, 84% successfully demonstrated the role that the landscape had on the outcome of restoration (de Souza 2013).

The authors also found the landscape context to have a positive influence on restoration effectiveness, specifically when neighboring patches with high habitat density were in proximity to restored areas. The metanalysis demonstrated that landscape-level factors are as important as site-specific factors in the outcome of the restoration and that future studies should incorporate landscape elements (de Souza 2013). Including landscape factors, like habitat cover, can help ecologists set more specific restoration outcomes based on the context of the surrounding landscape of the restoration site.

2.1.3. Habitat Cover Effects Observed in Restoration Efforts

Many studies assess the forest cover influence on wetland restoration projects using digital orthophotography and GIS (Alsfeld et al. 2010). For example, one study used concentric ring buffers to quantify the elements (e.g., streets, forest, developments, freshwater bodies) surrounding the center of 20 previously restored wetland communities. It was found that distance to the nearest forest was the most crucial variable contributing to the vegetation richness and percent cover wetlands, attributing the vegetation richness to spillover effects from the surrounding landscape. Another wetland study (Houlahan et al. 2006) found that surrounding forest cover was a significant variable contributing to the species richness found within the wetland restoration site. Both studies suggest that future restoration endeavors consider the surrounding forest cover in their projects, as proximity and percent cover show a positive influence on measures of restoration success, such as vegetation and species richness (Houlahan et al. 2006; Alsfeld et al. 2010). Similarly, both studies exemplify the use of aerial imagery and GIS in restoration efforts.

The interaction between restoration treatment sites and the surrounding forest cover, specifically on the dynamic between forest cover and observed bird communities, has also been studied in restoration ecology. Reid et al. (2014) studied the landscape-bird community dynamic on the same thirteen restoration site at Las Cruces Biological Reserve. There was an observed interaction between the local restoration efforts and the landscape context, affecting the composition of the bird communities observed at the restoration sites. Specifically, areas with higher forest cover had a higher representation of bird communities from the surrounding landscapes at the restoration sites. The implication of these findings suggests that restoration projects near regions with high forest cover can expect bird visitation from communities that are representative of the reference habitat, an essential concept in restoration ecology as specific bird species act as propagules for seed dispersion (Reid et al. 2014). In this context, GIS and aerial imagery were used to examine the effects of surrounding forest cover on biotic factors such as bird communities, and the implications demonstrate how spatial analysis can lead to more informed decision making relating to restoration practices.

Reid et al. (2015) conducted a subsequent study based on the previous findings by Reid et al. (2014) that examined the effect of forest cover on seed rain establishment for the same restoration project at Las Cruces Biological Reserve. Since high forest cover had shown to be positively correlated with the presence of bird communities in restoration, it was expected that seed rain – the falling of wind-dispersed seeds —would be similar in restoration sites that of surrounding reference forest (Reid et al. 2014). Contrastingly, Reid et al. (2015) did not observe a relationship between seed rain and forest cover at 100- and 500-meter buffers around the restoration sites, suggesting that surrounding forest cover is not a significant factor for seed rain establishment in restoration sites. Nonetheless, they suggest that the effects of habitat cover on restoration sites should be observed over time, as the composition of the surrounding forest and restoration sites will continue to change.

Active restoration practices have been shown to assist the rate of regeneration in deforested landscapes, and the effect that habitat cover has on seed recruitment has also been studied (Holl et al. 2017). By using forest cover as a landscape variable, it was hypothesized that higher seed recruitment –the establishment of seeds in a region—would be observed in plots with higher areas of surrounding forest cover, due to the higher availability of seed dispersers in these regions, as demonstrated in previous studies (Munro et al. 2007; Reid et al. 2014). Contrastingly, they found no strong evidence for surrounding forest cover effects on seed recruitment. They hypothesized a more substantial landscape effect would be detected if individual tree species were used, rather than a total area forest cover, since other studies have shown that distance to parent trees affected the dispersal of seeds (de la Peña-Domene, Minor and Howe 2016). Nonetheless, they explain that given the extent of the study, incorporating specific tree species is impractical at larger scales.

Although forest cover has been used as a variable to predict outcomes, forest cover changes at each site have not been directly studied against the topographic variations in the underlying region. The thirteen restoration sites were placed in various regions near LCBS, each with distinct elevations and with varying degrees of surrounding forest cover. It is essential to consider how restoration outcomes can be explained by the variations in the context of their location.

2.2. Topographic Variables and Regression Analysis

2.2.1. Influence of Topographic Variables on Restoration Outcomes

Other studies have sought to identify and evaluate the biophysical variables that affect forest recovery in tropical regions. Variables such as elevation and aspect have shown to have a relationship on forest recovery. Forest recovery, particularly natural reforestation, is more commonly observed at higher elevations with steep slopes as these regions are more isolated and less affected disturbances such as agriculture due to unsuitability (Thomlinson 1996). Aspect is similarly thought to affect forest recovery, as regions respond differently to varying amounts of sunlight. For example, in the northern hemisphere, south-facing slopes receive more sunlight and consequently less favorable for tree growth (Maren et al. 2015).

For areas undergoing restoration and reforestation, it is crucial to understand what factors influence the observed changes in vegetation cover. Regression analyses are used in studies to understand the relationship between different variables. For example, given the topographic profile of a region, can we see a relationship between these variables and the changes in vegetation growth. Crk et al. (2009) investigated the relationship between forest recovery and landscape variables using logistic regression. It has been observed that forest recovery is more likely observed at higher elevations and steeper slopes (Thomlinson et al. 1996). Crk et al. (2009) sought to identify the landscape-level factors that determine forest recovery in regions in Puerto Rico previously used for agriculture. Their study used Landsat imagery and the topographic variables elevation, slope, and aspect. Slope and aspect were derived from the Digital Elevation Model (DEM). Of the studied variables, they found that slope and aspect were the most important predictors of forest recovery, and, overall, the model was useful at predicting the spatial pattern of forest recovery for use in land use planning and recovery studies (Crk et al. 2009).

The findings of Crk et al. suggest that slope and aspect could be strong predictors of the observed recovery observed at the restoration sites in Costa Rica. Likewise, this study will examine how the topographic variables, slope percent rise, aspect, and elevation influenced the gain in forest cover surrounding the thirteen restoration sites by Zahawi and colleagues (2013). Can we attribute the variation in forest cover gain in and surrounding the restoration sites to the variations in topography?

The implications of this study would allow restoration ecologists to understand better the variables influencing restoration outcomes in Costa Rica as well as help make better-informed decisions regarding sites to prioritize. For example, if this study found that reforestation rates in Costa Rica are inherently greater at higher elevations, then ecologists could prioritize implementing active restoration strategies at lower elevations and allow natural regeneration to occur in other areas. Likewise, if the variations in slope and aspect between the sites can explain the disparity in forest gain outcomes, then restoration ecologists would be able to anticipate better restoration outcomes as well as implement strategies that consider the landscape.

2.3. Assessing Change in Forest Cover using Aerial Imagery

2.3.1. Acquisition of Aerial Imagery

Remote sensing (RS) has often been used to monitor land cover and land-use changes, in particular, those resulting from human activities such as deforestation and forest regeneration (Read, Denslow, and Guzman 2001). RS technologies allow users to collect information about the earth using cameras, satellites, or sonar systems (Read, Denslow, and Guzman 2001). RS offers a more practical approach to assess forest cover, especially in large-scale projects in remote regions where in-situ field checking methods are more like to be challenging. RS through aerial imagery is the process of acquiring obtained through aircraft such as helicopters and fixed-wing vehicles. More recently, unmanned aerial vehicles (UAV's) have also proved to be a viable method for obtaining high-quality imagery for use in forest cover studies (Zahawi et al. 2015). This study will rely on remote sensing technologies, specifically aerial imagery, to quantify the changes in forest cover in a remote area of Costa Rica.

2.3.2. Quantifying Forest Cover through Aerial Imagery

Various studies have utilized aerial imagery to quantify forest cover (Nowak et al. 1996; Walton et al. 2008). Simply, the interpretation of aerial imagery in forest cover studies involves detecting the presence or absence of forest cover from aerial photographs through a GIS and is made in through a variety of methods. Aerial photographs need to be interpreted by someone who can discern tree canopies. Typically, leaf-on imagery is interpreted, although skilled interpreters can infer canopy from tree branches in leaf-off imagery (Walton et al. 2008). The resolution needed to interpret tree cover, specifically digital images, is generally 1 meter, although high-resolution imagery is larger in size and more time-consuming to process (Walton et al. 2008).

One example is demonstrated in a study by Nowak et al. (1996) in which they quantify urban tree cover in the United States (U.S.) using aerial imagery, which they regard as a cost-efficient remote sensing method to analyze cover. The method involved scanning aerial imagery quantify tree cover in the urbanized cities across the U.S., in which cover estimates were hand-digitized by a photo interpreter using GIS. Nowak et al. (1996) explain that although scanning aerial images is the most precise and detailed method of analyzing forest cover, it is labor-intensive and conditional on the skill of the photo interpreter. The study was successful in quantifying coverage, and it was also discovered that urban tree cover was primarily affected by the surrounding natural environment. Additionally, the authors note that GIS and tree cover data can be used to assess landscape-level features – such as forest fragmentation, patch sizes, and connectivity – because it provides a baseline for assessing forest cover change as well as reveal patterns in the landscape (Nowak et al. 1996).

Aerial imagery is digitized by creating polygon or raster files that signify forest cover regions that correspond with the underlying aerial image using a GIS. Digitizing requires one to trace georeferenced imagery to create raster, line, or polygon layers to create digital data, which can then be used for spatial analysis. Spatial analysis tools can then be applied to the raster or polygon representing forest cover using GIS. However, the accuracy of the features representing forest cover depends on the image resolution (Pelz and Dickinson 2014). Although automated methods exist to digitize aerial imagery, the hand-digitization of smaller regions can result in more accurate raster layers when done by users who are familiar with the area, as was done in this study (Cunningham 2006). Similarly, an adequate measure of forest cover quantity can be obtained from aerial images, but more specific distribution measures of vegetation types and classes are much more difficult to assess (Walton et al. 2008). Therefore, most forest cover studies utilizing aerial imagery focus on structure and quantity analyses (Walton et al. 2008).

Monitoring forest cover through aerial imagery offers a low-cost method of assessing spatial patterns in forest cover through GIS. Workflows can be quickly established, making forest monitoring through aerial imagery a reliant, repeatable, and appealing methodology for disciplines like restoration ecology. Zahawi et al. (2015) captured aerial images using a UAV in order to extract essential monitoring parameters – including canopy height biomass and canopy structure, to name a few— used in restoration to assess the progress of tropical forest recovery in Costa Rica. The goal of the study was to compare the accuracy of UAV results to those of traditional field-checking methods. Field-checking methods in remote regions are limited by funds and require more time, making temporal monitoring at large spatial scales unreliable through traditional approaches (Melo et al. 2013; Zahwai et al. 2015). The study UAV-obtained aerial images and used Ecosynth methods to develop a high- resolution 3D model of the study area. The Ecosynth Project consists of open source tools that help create 3D models of ecosystems using images obtained from UAV flyovers. The study found that aerial imagery and

Ecosynth produced results comparable to field measures, particularly for measuring above-ground biomass and percent openness parameters. The findings demonstrated the viability of aerial imagery, GIS, and drones for assessing forest structure in large-scale restoration studies.

Reid et al. 2018 used high-resolution aerial photographs (10-meter resolution) to quantify the persistence of secondary forests in southern Costa Rica between 1947-2014. The persistence of secondary forests refers to the maximum age (in years) that a secondary forest reaches before it is converted to other land types (Reid et al. 2017). The study examined six potential predictors of secondary forest persistence which included, distance to the nearest road, distance to the nearest river, mean elevation, slope, patch area, and distance to the nearest protected area. The study found that patch size and distance to the nearest river were strong predictors of forest persistence. For example, secondary forests at a 200-meter distance from the river were more 1.5 times more likely to be cleared than patches that were directly adjacent to rivers.

In the same way, forest patches of 14 hectares were half as likely to be cleared than patches that were 0.1 hectares. Slope and elevation were not reliable predictors of forest persistence. The study demonstrates the importance of evaluating landscape-level elements to understand the context of forest cover changes. Landscape-level elements are essential in the context of forest cover change. Identifying the variables that influence restoration outcomes will help restoration practitioners implement strategies that incorporate their influence in the decision-making process.

Chapter 3 Methodology

This chapter describes the proposed methods to assess the changes in forest cover for an on-going restoration project in southern Costa Rica, specifically surrounding thirteen treatment sites in Las Cruces Biological Reserve. The research methodology is based on a statistical analysis of data derived from aerial imagery and a digital elevation model. This study will attempt to understand the relationship between forest cover change, elevation, slope, aspect, and distance using regression analysis. Researchers at LCBS provided all data, and the information obtained from this study will be used in future studies to help better understand the landscape-level processes restoration treatments. Geographic analyses were performed using ArcGIS Pro 2.6.

3.1. Data Sources and Processing

The study will utilize four datasets (Table 1) consisting of two forest cover layers (TIFF), one treatment site layer, and a 5-meter DEM of the study region. The forest cover layers were obtained from high-resolution orthorectified aerial photographs of 2005 and 2014 and had a three-meter resolution. Aerial images were then hand-digitized by persons familiar with the landscape at LCBS. The digitization of aerial imagery included primary and secondary forests, live fences, individual trees, and hedgerows of all sizes as tree cover; all other areas were classified as no cover (Reid et al. 2014). The treatment site layer consists of thirty-nine polygons measuring ~50 x 50 meters and separated into thirteen sites. Each site contains a control, island, and plantation treatment (Figure 3). All the data were re-projected to the WGS 1984 UTM Zone 17N coordinate system using the Project Raster tool. An example of treatment site OM is shown in Figure 4 with the three different treatment plots (control, island, and plantation). The forest cover growth between the two years is also shown in Figure 4.

Table 1 Data Description

Layer	Date Collected	Contents	Spatial Resolution	Source & Format	Projection
Costa Rica Forest Cover	2005	Raster file from digitized aerial imagery of the same year	3m	Raster (TIFF) provided by Organization for Tropical Studies	WGS 1984 UTM Zone 17N
Costa Rica Forest Cover	2014	Raster file from digitized aerial imagery of the same year	3m	Raster (TIFF) provided by Organization for Tropical Studies	WGS 1984 UTM Zone 17N
Treatment Plot Locations	2005	Polygon files outlining the treatment plot locations	Polygon	Shapefile provided by Organization for Tropical Studies	WGS 1984 UTM Zone 17N
DEM Study Area	2013	Digital Elevation Model of Southern Costa Rica	5m	Raster (TIFF) provided by the Organization for Tropical Studies	WGS 1984 UTM Zone 17N

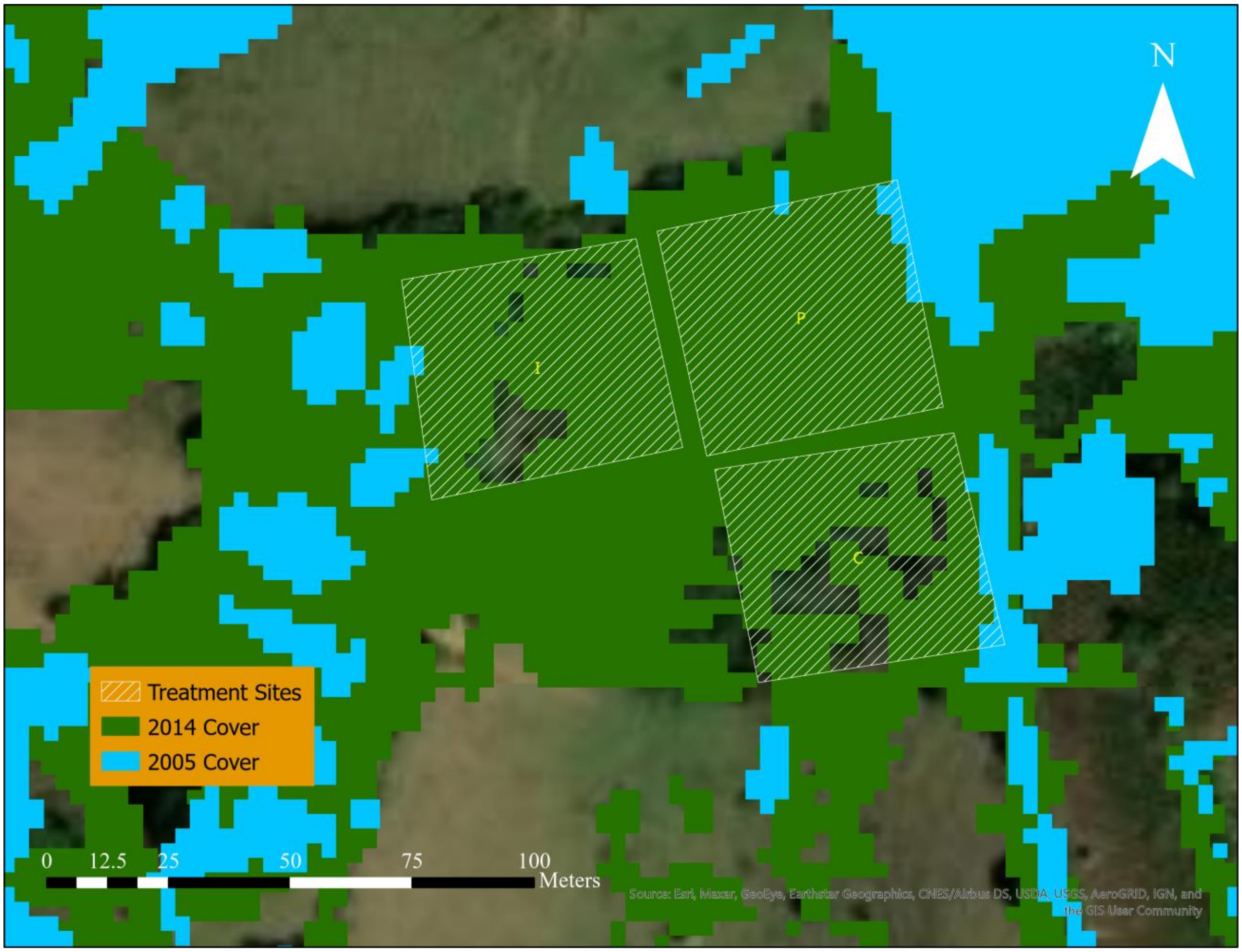

Figure 4 An example of one of the treatment site locations (Site OM). There are 13 sites scattered through various regions within the study area boundary. Each site has three treatments (control, island, and plantation) with varying setups.

Table 2. A list of the thirteen restoration sites with three treatments at each site. The area refers to the plot size of each treatment (~50 x 50 meters).

Site	Treatment	Area (sq.m)
AC	P	2343.0
	C	1990.5
	I	1769.8
BB	P	2466.0
	I	1891.6
	C	2302.9
EC	P	2384.8
	I	2379.7
	C	2216.8
GN	P	2303.5
	I	2241.0
	C	2182.4
HB	P	2312.2
	I	2279.3
	C	2216.9
JG	P	2501.7
	I	2021.4
	C	2219.3
LL	P	2414.4
	I	2340.9
	C	2248.8
MM	P	1881.4
	I	2109.0
	C	1887.5
OM	P	2368.5
	I	2266.3
	C	2245.9
RS	P	2152.9
	C	1477.3
	I	1717.8
SC	P	2378.4
	I	2110.7
	C	2148.9
SG	P	2488.1
	I	2115.4
	C	2018.1
SP	P	2452.9
	I	2272.0
	C	2380.7

3.2. Workflow and Data Analysis

The next section outlines the workflow of the data analysis portion of the project (Figure 4). The process is divided down into four main steps. The first section involves preparing the data preparation, which involves the creation of the study area and raster projections. Next in the workflow is the analysis of forest cover change using the Raster Calculator tool. A multiple ring buffer analysis will also be conducted to provide baseline data for each of the thirty-nine treatment sites. Finally, a regression analysis will be performed to discover any relationships between the changes observed and topographic variables derived from a 5-meter digital elevation model.

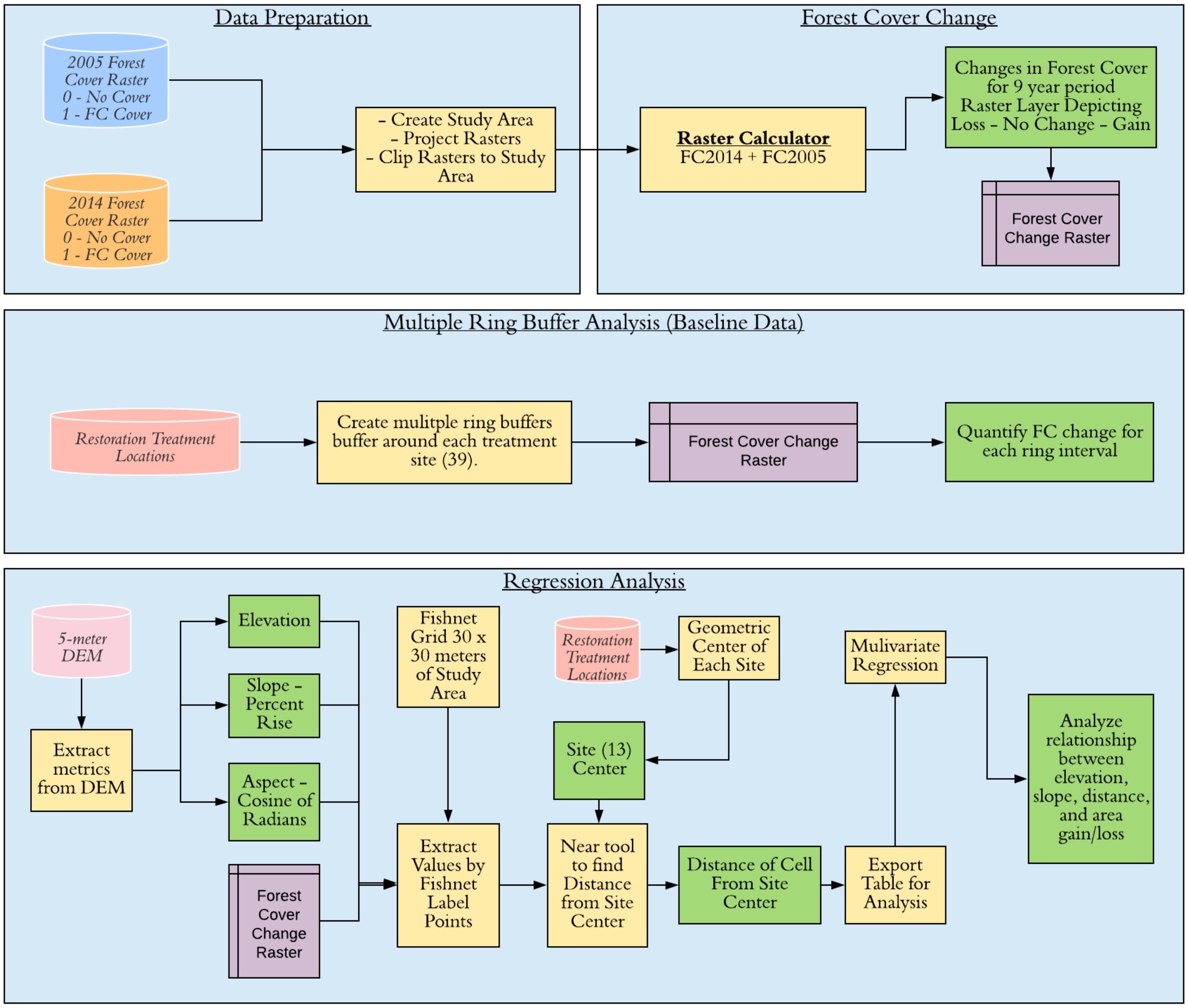

Figure 5 The workflow is summarized into four sections. The database symbol represents the datasets used in the study. The purple box represents the change in forest cover layer. Green boxes represent input and outputs of the workflow. Yellow boxes represent an analysis step.

3.2.1. Data Preparation

This study focuses on assessing forest cover change in the areas in and surrounding Las Cruces Biological Reserve. The confines of the study area were created by finding the overlapping regions from 2005 and 2014 forest cover layers using GIS. A polyline feature was created to outline the extent of each forest cover layer and was then joined using the Union tool. The polygon layer representing the overlapping regions was then exported using the Export Features tool resulting in the boundary of the study area (shown in Figure 6). The 2014 forest cover layer had a more considerable extent and was clipped to overlap with the 2005 forest cover layer. The northeast 2014 cover layer shows a highly forested region in Costa Rica.

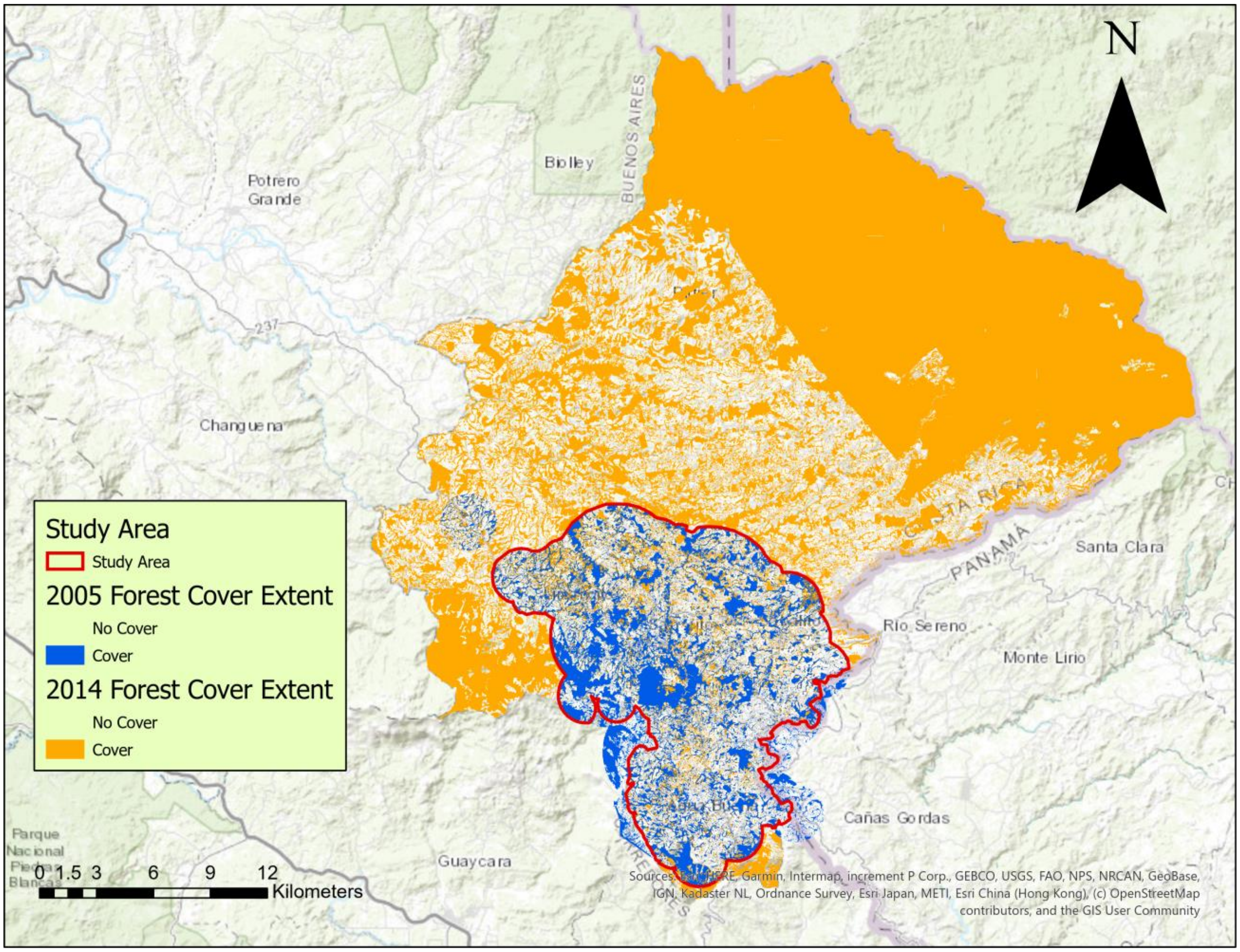

Figure 6 The map shows the extent of the 2005 and 2014 forest cover layers. The study area is the region where both forest cover layers overlap. The 2014 forest cover layer had a much larger extent than the 2005 layer and was clipped using the study boundary layer.

3.2.2. Forest Cover Change

To calculate the change in cover, the forest cover layers were clipped to the same study area using Extract by Mask tool. The Raster Calculator tool was then used to assess the changes in forest cover for nine years. Before the raster calculator could be run, both raster files had to be resampled from their initial values of 0 (no cover) and 1(cover). The 2014 cover raster was resampled so that areas of no cover were represented by the number 2, and areas with forest cover were represented by the number 3. Similarly, the 2005 raster was resampled so that regions with no cover were represented by the number 5, and areas with forest cover were represented by the number 6. This was done to ensure that when these two rasters were added, they would produce four unique values describing the possible change outcomes. For example, if these rasters remained binary (0,1), then adding them would result in three possible outcomes (-1, 0, and 1), with 0 representing areas of no change, which does not allow us to discern whether these regions were cover and remained cover, or if they were no cover and remained no cover.

In adding the 2014 cover layer to the 2005 layer, we can see which areas (cells) experienced gain, loss, or no change in forest cover. Figure 7 illustrates the logic behind the Raster Calculator tool. An additional raster cell reclassification will be performed to separate the regions that experienced no change to quantify which areas remained cover and which remained no cover.

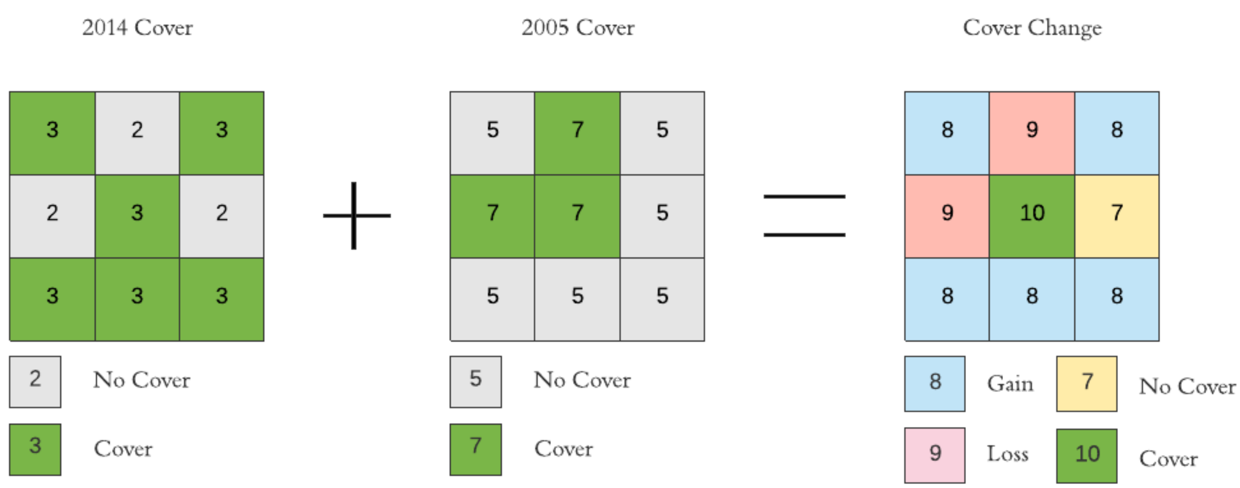

Figure 7 Illustration of how forest cover change was assessed using the Raster Calculator tool.

3.2.3. Multiple Ring Buffer

A multiple-ring buffer analysis was conducted to calculate changes in forest cover for each of the thirty-nine treatments, or areas of interest (AOI), at various ring intervals from the plot and supplement the ongoing research at these restoration sites. For each of ~ 50 x 50-meter treatment plots, 11 concentric rings were placed at 50- to 1000- meter intervals, as shown in Figure 8. From 50- to 200- meters, the rings were created at 50-meter intervals. Ring buffers from 200 – 1000 meters from the plot were placed at 100-meter intervals.

Figure 8. The input setting used in the Multiple Ring Buffer Tool

The rings were created using the Multiple Ring Buffer Analysis tool (Figure 8). The treatment plots (39 AOI's) were used as the input features. The Dissolve Option was set to non-overlapping rings so that the output would result in individual rings that did not cover the area of the input feature. For example, the 50-meter ring covers the distance from the edge of the input polygon and 50-meters outward. The 100-meter ring covers the area from 50- to 100-meters and does not include the smallest ring. Figure 9 shows the multiple ring buffer configuration output. Additionally, this study is only interested in assessing forest cover surrounding the treatment site, or the input polygon, and, therefore, the area inside the input buffer was excluded.

Although the multiple rings will overlap for each of the treatment plots, this analysis is interested in extracting forest cover for each of the treatment sites so they can be studied individually in the future.

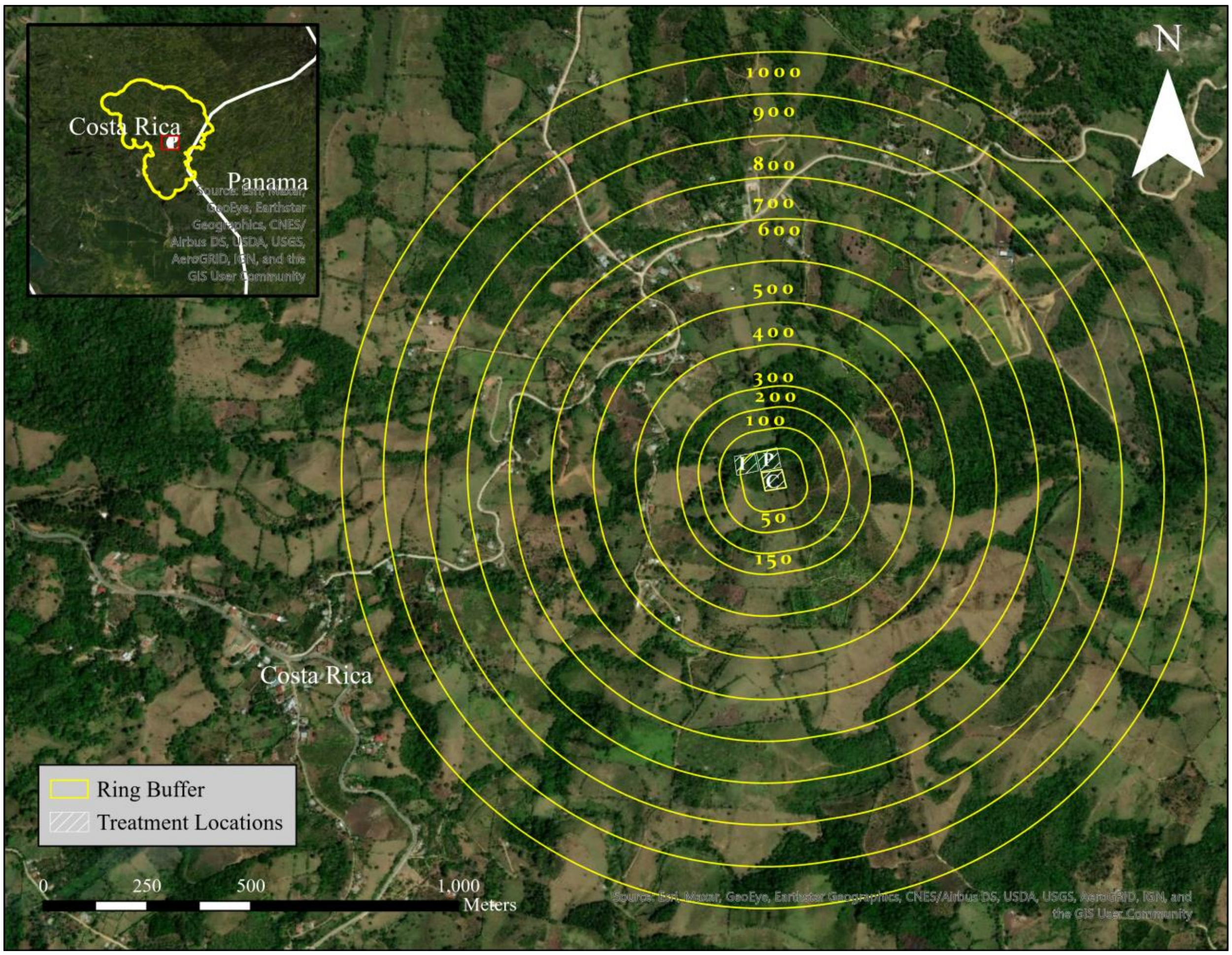

Figure 9 Multiple Ring buffer at site OM for the control treatment. This shows one site with three treatments. The multiple ring buffer will be created for each treatment (39 multiple-ring buffers).

Once the rings were created, the Intersect tool was used to find the forest cover change regions within each circle. To do this, the cover change raster was first converted to a polygon using the Raster to Polygon tool, since the Intersect tool only works on Feature Layer files. To quantify the cover change within each ring, a workflow was created to quantify changes for each ring at each of the sites, since there was a total of 429 rings between all sites.

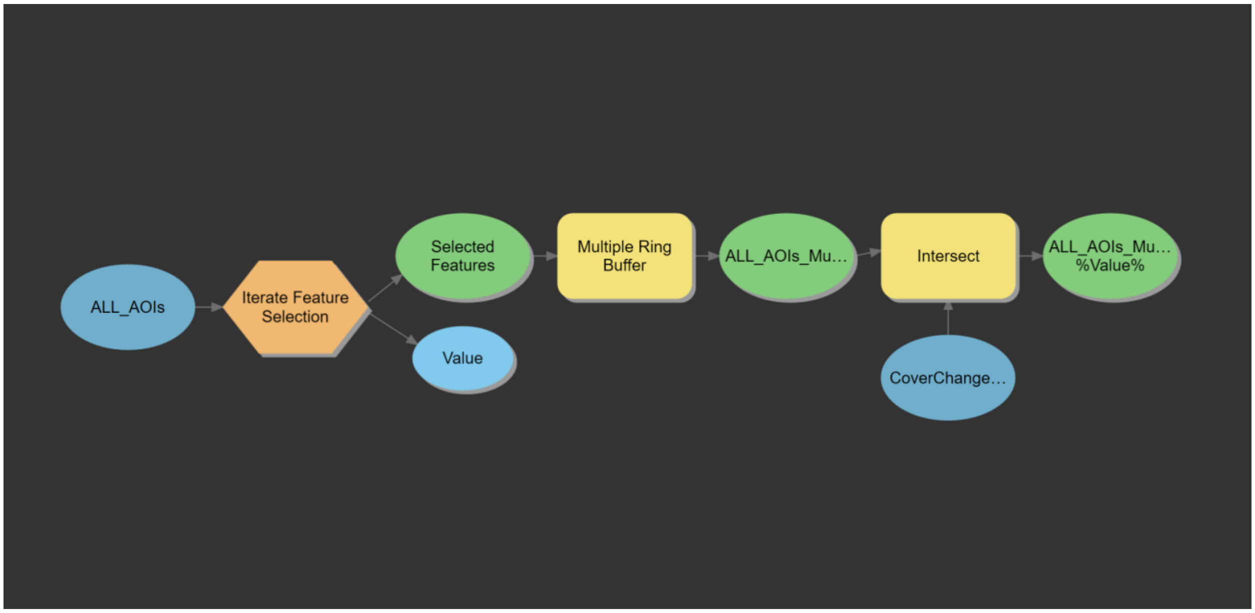

Figure 10. The ModelBuilder workflow is used to quantify the cover changes within each ring buffer. This process was automated since it would be too time-consuming to analyze each ring manually.

The model in Figure 10 shows how the forest cover changes for each ring interval was quantified. For each of the treatment plots, or AOI's, multiple ring buffers were created, as shown in Figure 8. After the buffers were created, the Intersect tool was used to find the polygon areas of forest cover within each ring for each of the treatment plots. The Intersect tool works by intersecting the ring polygon with the forest cover layer polygon, extracting the regions where they both overlap.

3.3. Regression Analysis

This study also investigated the relationship between forest cover gain, elevation, aspect, slope, and distance in a 200-meter area surrounding each of the thirteen restoration sites. First, a

30 x 30-meter grid was created using the Create Fishnet tool. Grid label points were also created to derive the study variables within each cell. The grid was used as a container from which to extract the variables percent gain, mean slope rise, mean aspect, and mean elevation values from multiple raster datasets (Figure 11). The grid was created using the Create Fishnet tool, and the cell width and height was set to 30-meters. The geometry type was set to polygon, and the extent was set to that of the study region using the study area boundary layer as the input feature. Figure 14 shows the 30 x 30 fishnet grid at one of the research sites (OM).

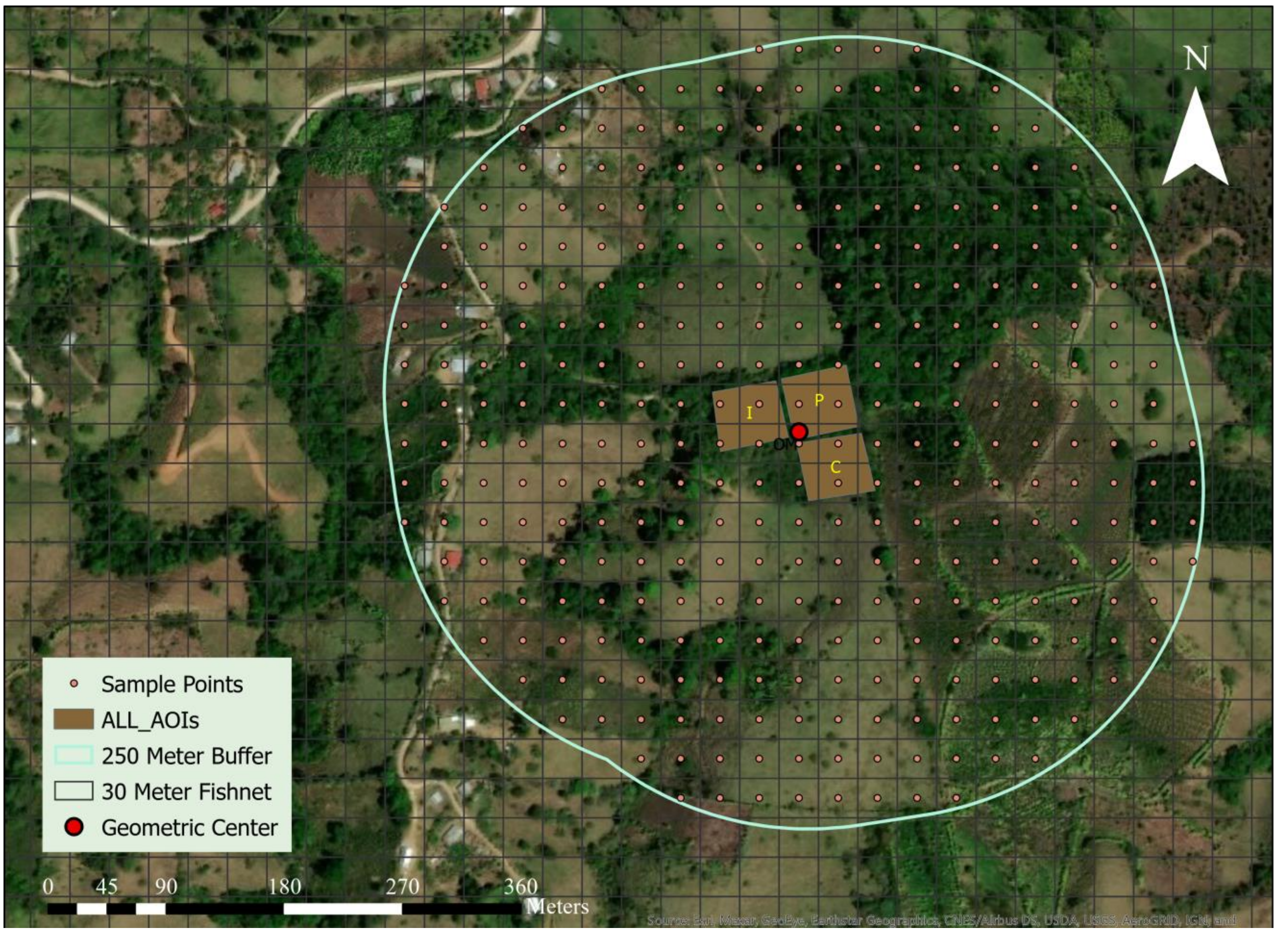

Figure 11 The study extent for the regression analysis. Each point corresponds to a 30 x 30 -meter grid. This was done for each of the 13 sites in the study.

The 5-meter DEM contains the elevation data, which was clipped to the extent of the study region (Figure 12). The Zonal Statistics as a Table tool was then used to calculate the mean elevation within each grid cell. Each grid cell contains a unique identified which will be used to group multiple variables at each grid cell location.

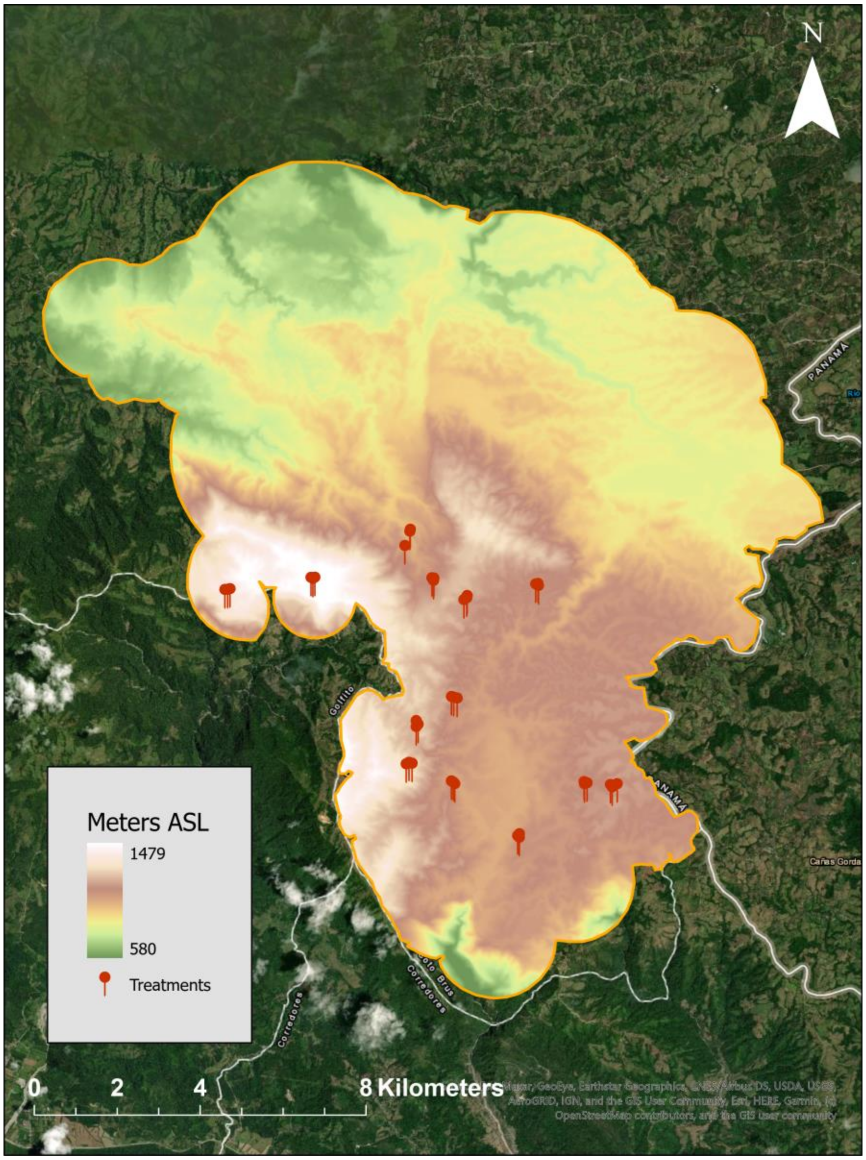

Figure 12. The elevation profile for the study region in meters. The map shows the different elevations of where the treatments are found.

The percent rise of the surface, or slope, was calculated using the Slope tool using DEM as the input feature (Figure 13). The percent rise is the inclination of the slope calculated as percent values, which range from 0 to infinity. A flat surface is represented by a value of 0, while a 45-degree surface would have a rise in the slope of 100%. A high percent slope value represents a more vertical surface. The output of the Slope tool is shown in Figure 13. Once calculated, the mean slope was obtained using the Zonal Statistics as a Table tool. Each grid has a corresponding grid label, which was used to extract the variables within each grid cell.

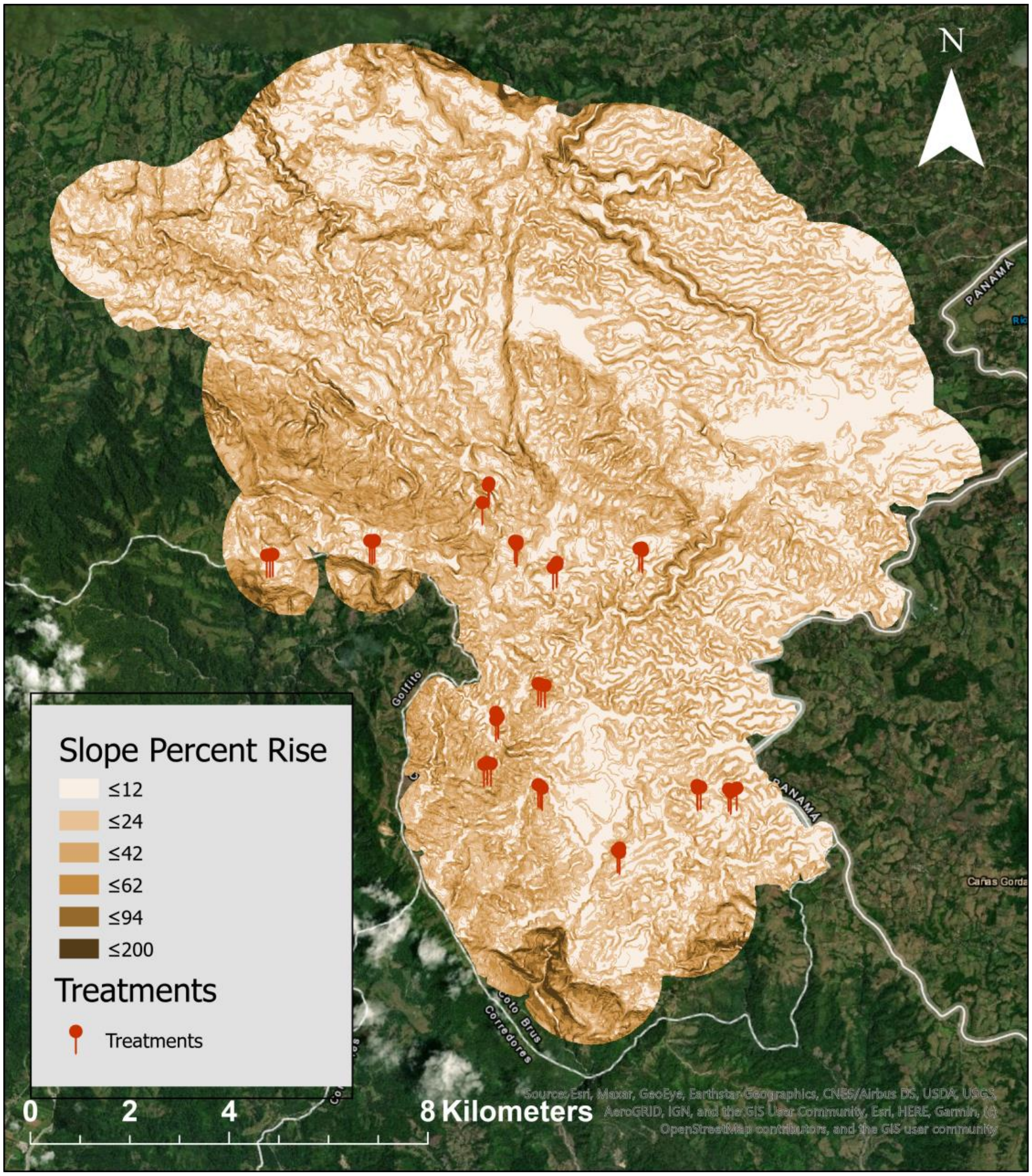

Figure 13. The output of the Slope tool. The red points represent the location of the treatment plots. Each site has varying slope values.

The aspect was derived using the Aspect tool using the 5-meterDEM as the input feature. Running the aspect tool provides an output in degrees, which is a circular measurement. All variables must be linear to perform a linear regression analysis. The Raster Calculator tool was used to transform aspects into a linear variable. The aspect output was first converted to radians, and then the cosine function was used. The aspect values (in degrees) were first converted to radians and then divided by 180, as shown in the equation below:

$$1° = \frac{pi}{180} radians$$

Next, applying the cosine function to the radian values generated a variable between 1(north) and -1 (south). In contrast, if one wanted to discover how east or west a surface faces, they would apply the sine function to the radian value. This study is only interested in the effect that north and south-facing slopes since, in the northern hemisphere, south-facing slopes are typically warmer, drier, and less conducible to vegetation growth. The equation used in the Raster calculator is shown in Figure 14.

$$Cos(\frac{math.pi * \text{Aspect\_5meters}}{180})$$

Figure 14 Equation used in Raster Calculator to transform aspect from degrees into a linear variable.

The output of aspect transformation is shown in Figure 15. The values range from negative one to positive one corresponding to south-facing and north-facing aspects, respectively.

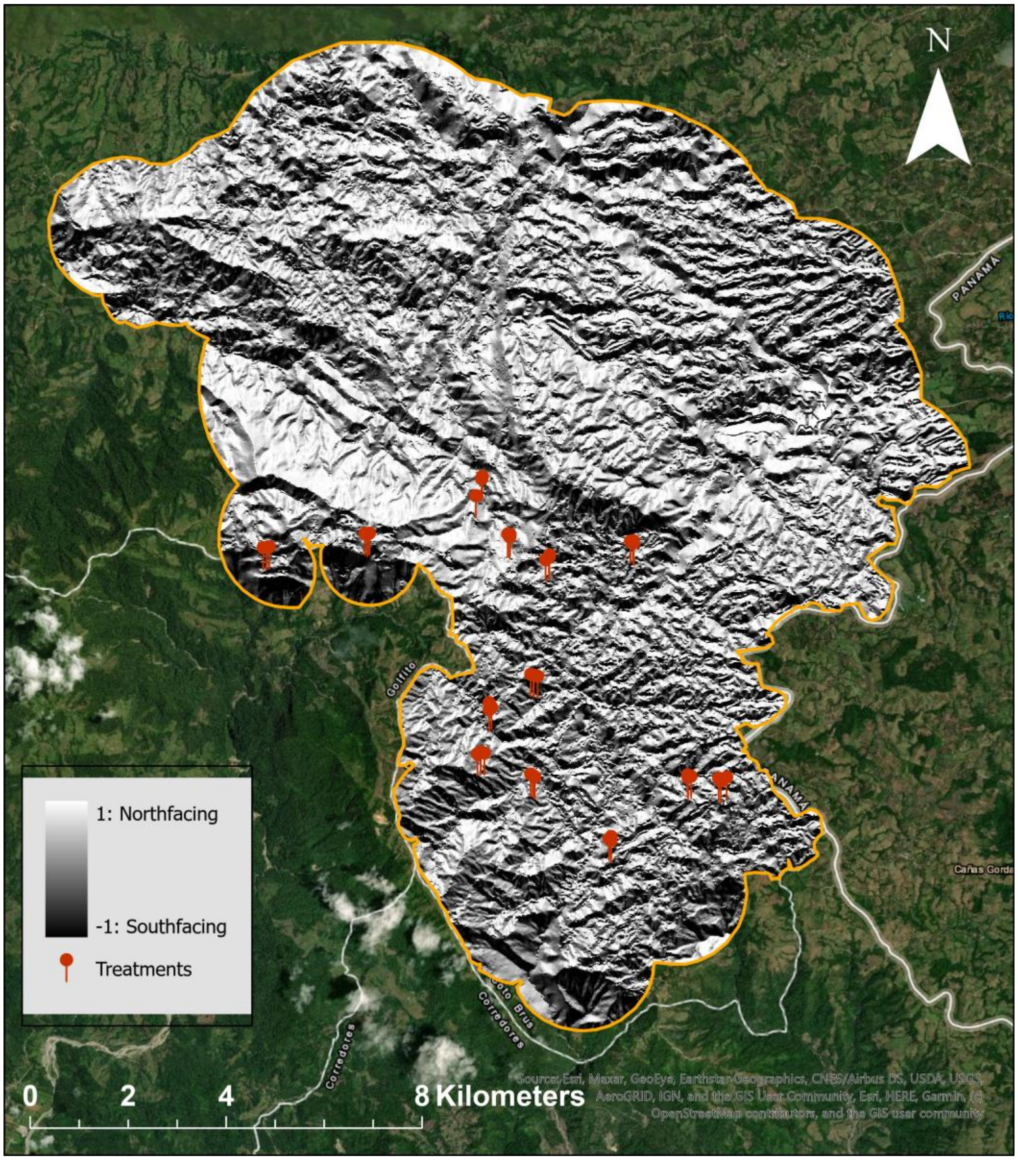

Figure 15. The result of converting aspect into a linear measurement.

The final variable used in the regression is the distance from the site, specifically the three treatment plots' geometric center. Before calculating the center of the study sites, a 200-meter buffer was created surrounding each treatment plot using the Buffer tool. The rings were dissolved to create a single polygon, and the geometric center of the polygon was calculated using the Calculate Field Geometry tool. The geometric center of two restoration sites is shown in Figure 16. This study site took the geometric center of the study region as the region influencing the surrounding environment. The distance to the center was calculated rather than the shortest distance to the nearest site since each site had varying treatment configurations. Additionally, for the regression analysis, it is important not to sample the same area twice. For this reason, the 200-meter buffer distance was chosen since this is the minimum distance between site overlap.

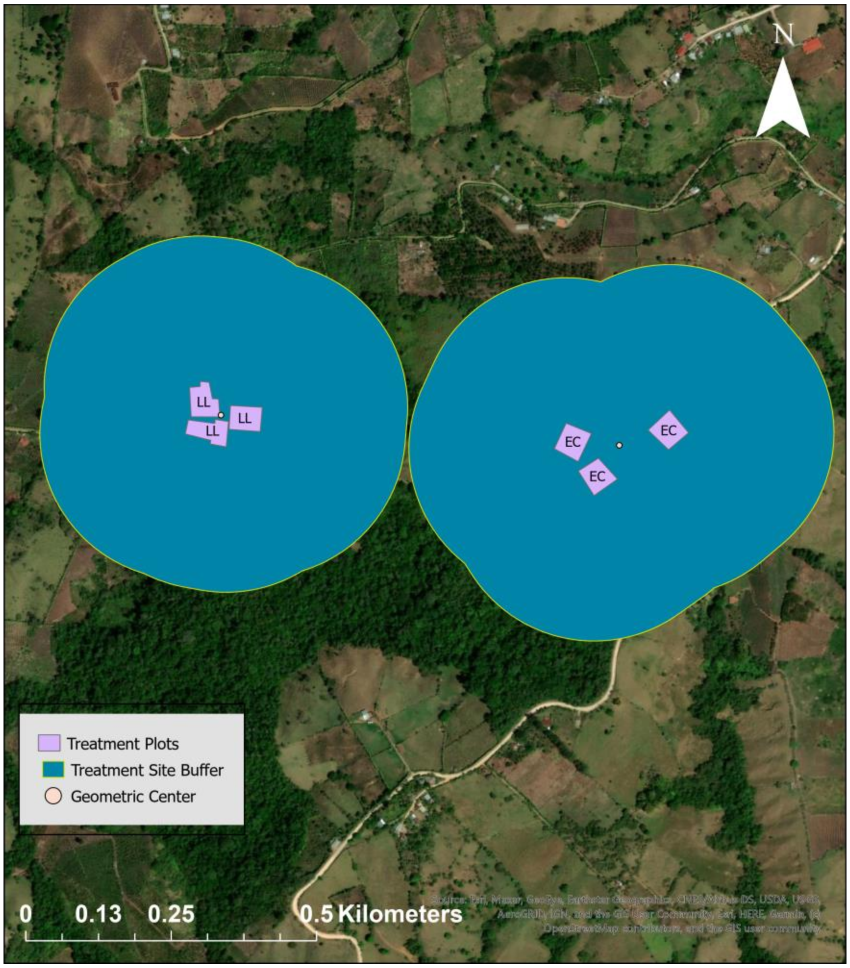

Figure 16 The map shows the buffer regions used in the regression analysis. For each of the sample points taken within the treatment buffer, the distance to the geometric center was recorded and used in the regression analysis.

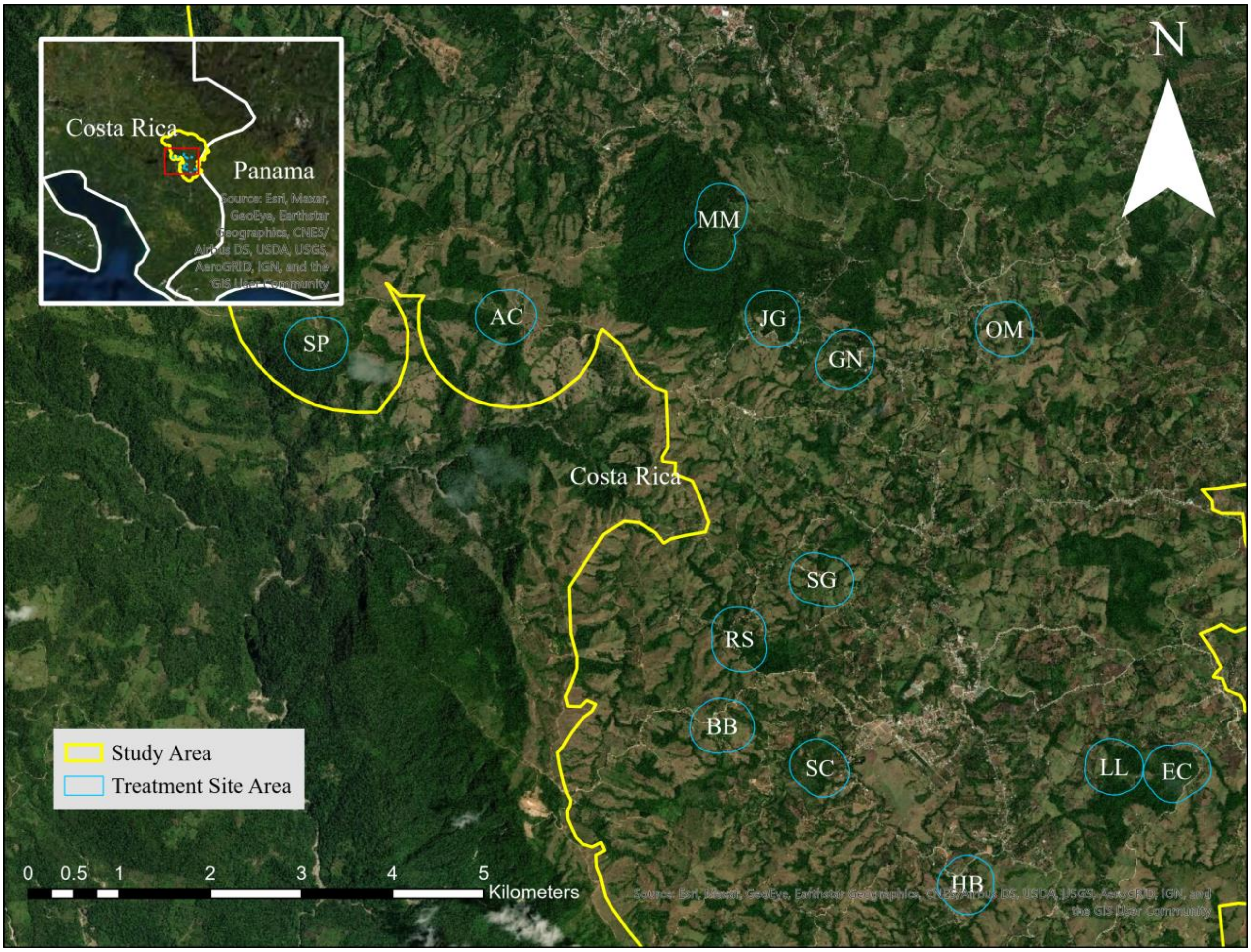

Figure 17 The map shows the 13 sites that were sampled in the regression analysis

The treatment site study area within the boundary of the study area is shown in Figure 17. Each treatment site area is independent of each other, and the point samples do not overlap into other treatment buffer boundaries. The sites vary in shape because of the differences in treatment plot configuration found at each site. This was another justification for using the geometric center of the study site to assess the relationship between forest cover gain and distance to the treatment study area. Lastly, the Zonal Statistics as a Table tool as a table was used to calculate the mean elevation, mean aspect, and mean slope within each 30-meter grid cell. Lastly, the distance from the center of each grid cell to the study site's geometric center was calculated using the Generate Near Table tool.

Chapter 4 Results

Chapter 4 describes the thesis results from GIS and statistical analysis. Section 4.1 presents the cover change analysis findings by treatment type, site, and general study area. This analysis provides baseline data for the ongoing and consequent projects near Las Cruces Biological Station as well as demonstrates how the study region has changed over nine years. Section 4.3 shows the findings from the multiple ring buffer analysis for the treatment plots. Section 4.3 outlines the results from the multiple linear regression, which will investigate the relationships between percent cover gain, elevation, aspect, slope, and distance surrounding the thirteen treatment sites.

4.1. Forest Cover Change

The forest cover change analysis showed revealed a ~15% increase in cover between 2005 and 2014 for a study area spanning approximately 20,400 hectares. Additionally, the analysis showed a 5% decrease in forest cover. Regions that experienced no change over the nine years comprised ~ 80% of the study area. Overall, there was a net increase of about 9.7% between the two time periods. Figure 13 illustrates the forest cover change for nine years. Table 3 lists the quantified categories of changes.

Table 3 Quantified forest cover change between 2005-2014. The rows cover, and no cover represent regions that experienced no change.

Change	**Area (km)**	**Hectares**	**Percent %**
No Cover	103864	10386.4	50.8
Gain	30086	3008.6	14.7
Loss	10296	1029.6	5.0
Cover	60095	6009.5	29.4
Total	204,342	20,434.2	100.0

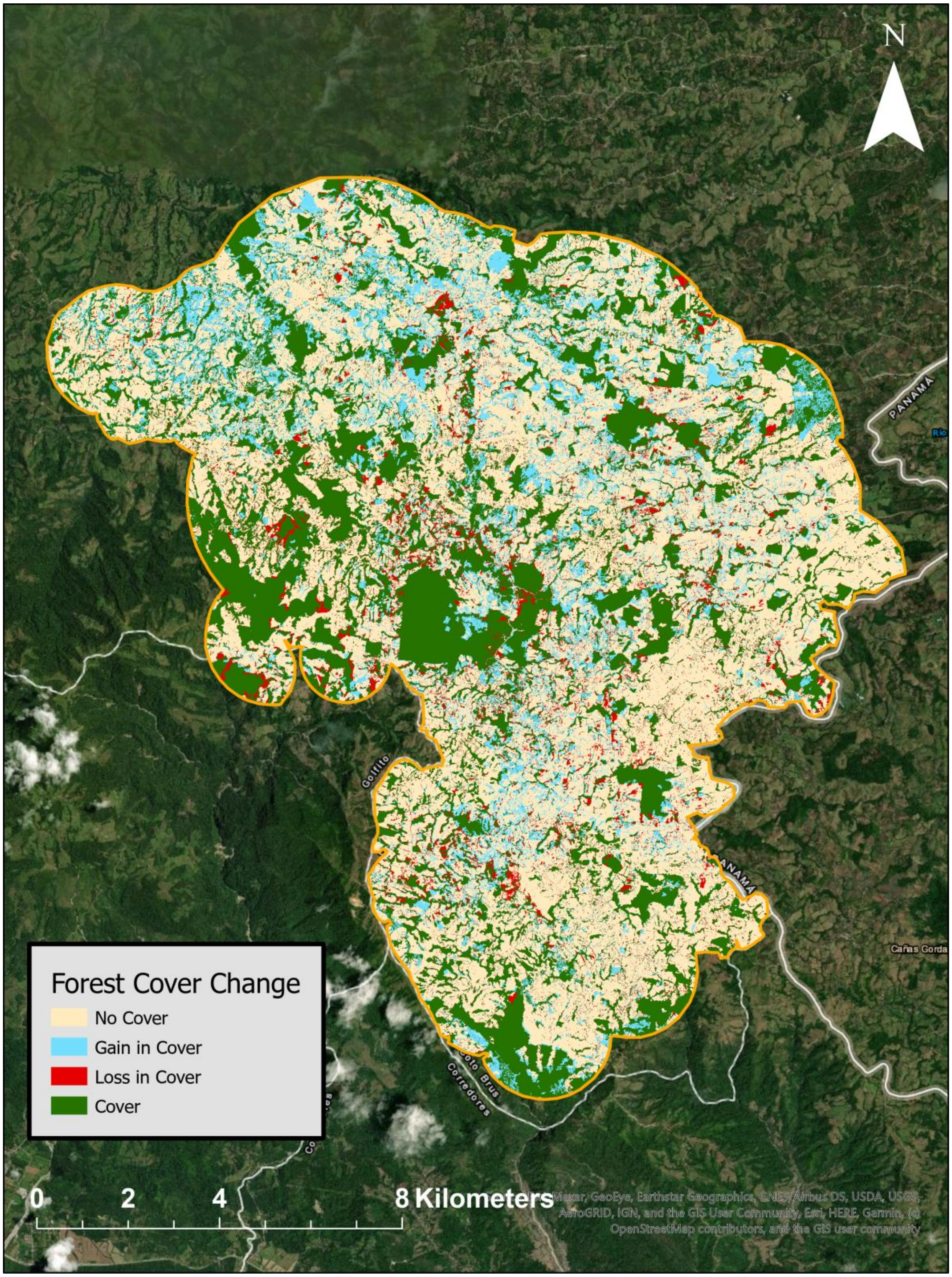

Figure 18 Changes in forest cover between 2005 and 2014. Areas in blue have experienced a gain in cover. We can see that horizontal growth in vegetation on the edges of larger forest patches.

Figure 19 shows a 3D model of the study area based on the 5-meter digital elevation model. The 3D model can show the variations in the topography of the study area better than a flat map. In the map, areas in red experienced forest cover loss and areas in blue experienced forest cover gain Forest cover loss and gain are shown at a 3-meter raster resolution.

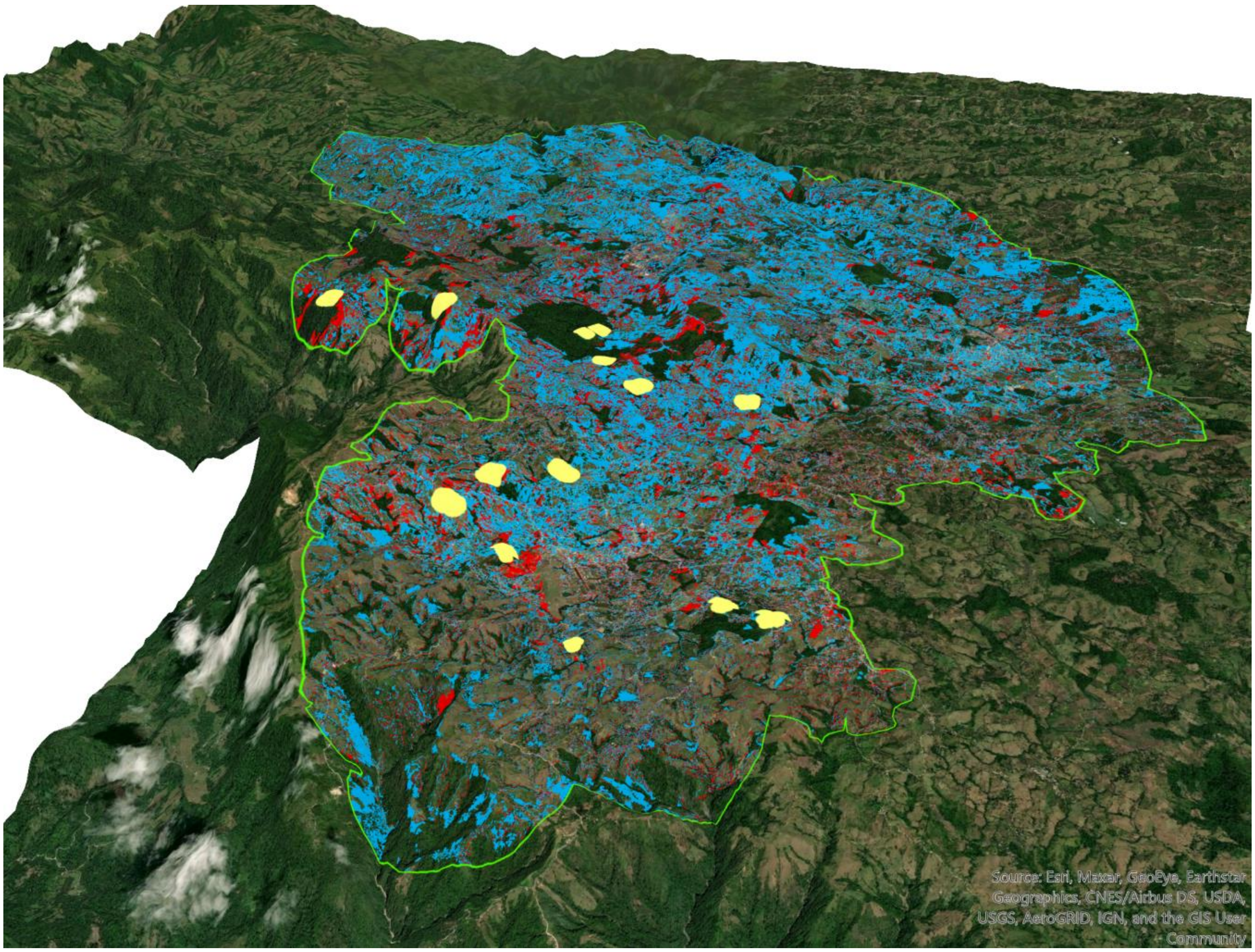

Figure 19 A 3D model of the study extent shows the treatment sites within the context of the topography. The 5-meter DEM was used to generate the surface. The surface relief was exaggerated by a factor of 2 to show the variation in landscape better. Areas in yellow are the location of the treatment sites. Blue regions are regions that experienced a gain in forest cover, and the red areas are those that suffered a loss in forest cover.

4.2. Multiple Ring Buffer

The multiple-ring buffer analysis was conducted for 39 treatment plots across 13 different sites. Figure 11 shows the multiple ring buffer for the control plot at one of the 13 sites. The three treatment plots at each site in all cases overlapped the ring buffer areas. The goal of this was to quantify each treatment site individually so they could be studied independently from each other in future studies. The multiple-ring analysis found that areas closer to the center of the site experienced higher forest cover increases. This was expected since the regions within 50 meters contain the other treatment plots where there was active reforestation.

Regions at a 100-meter distance from the site experienced the second-highest mean percent increase in forest cover. Although we generally observe a higher mean percent increase in regions closer to the treatment plots, this trend does not consider how regions further from the center covered a much greater area. For example, the ring buffer at a 900-meter distance covers a circular area with likely higher variations in topography and landscape, particularly at opposite ends of the buffer. Also, rings at 1000-meters from the plots covered 58,000 square meters, while the 50-meter distance ring covered an area of 18,000 square meters (Table 4).

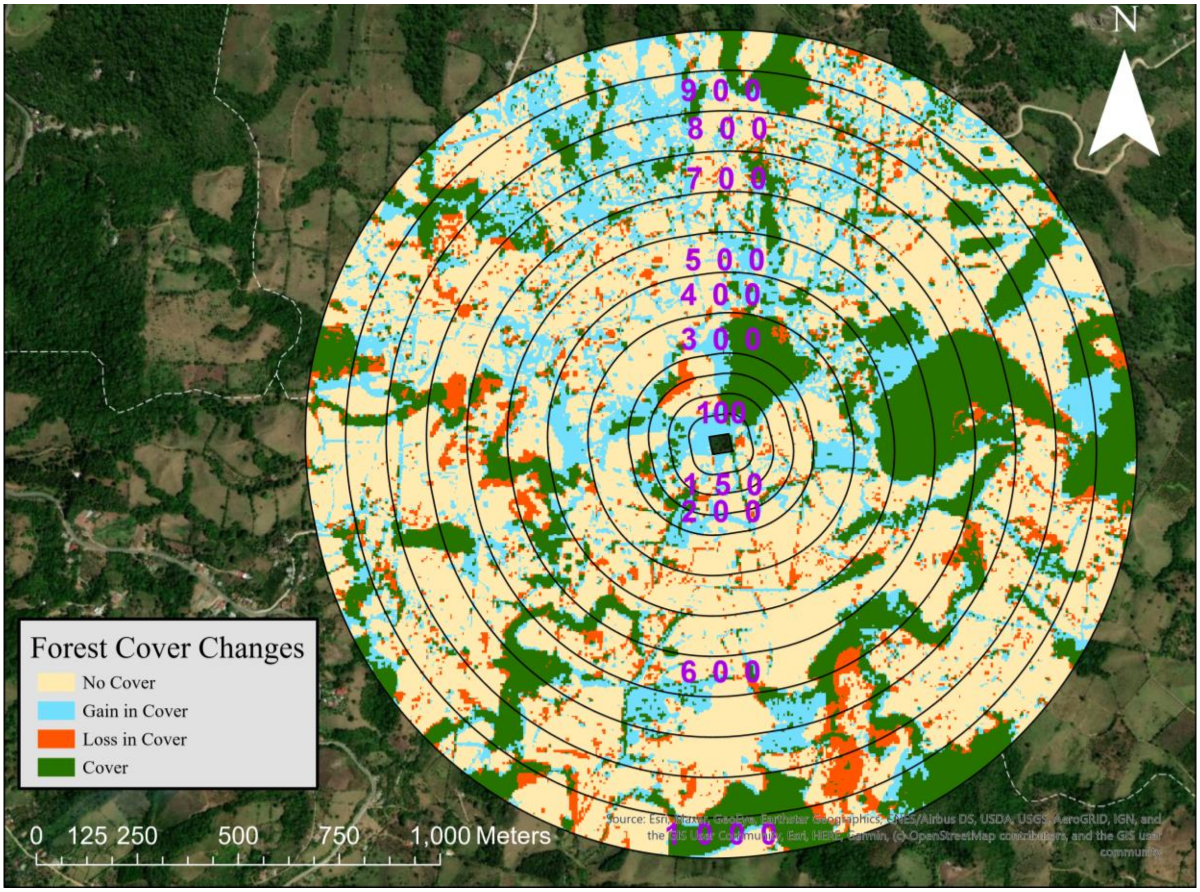

Figure 20 One example of the ring buffer analysis was conducted. This was performed for 39 treatment plots across 13 sites. The ring buffers overlapped due

Table 4 Multiple Ring Buffer distances with mean percent changes at each buffer distance across 39 treatment sites.

Distance	Gain (%)	Loss (%)	No Cover (%)	Cover (%)	Total Area
50	**25.8**	4.8	30.4	38.9	17595.0
100	17.6	6.4	29.2	46.8	33480.8
150	14.7	7.1	33.5	44.8	49073.7
200	13.9	6.6	36.0	43.6	64757.4
300	13.4	7.1	41.2	38.4	176593.8
400	12.9	**7.5**	45.3	34.3	239375.0
500	13.4	7.5	43.8	35.4	302159.9
600	14.5	6.4	45.4	33.7	363677.3
700	14.1	6.3	46.7	32.9	421216.9
800	13.5	6.0	48.3	32.2	479144.0
900	13.2	5.9	48.5	32.4	537056.7
1000	12.4	6.0	49.6	32.0	578025.5

The average percent gain in cover across the sites ranged between 5% and 25%, with the highest percent increase in the total area seen at Site OM (Figure 12). The lowest increase in forest cover was observed at site LL with a mean increase of 5% across the three plots. The highest percent loss was observed at site SC with an average of 12%. The lowest percent loss in cover was recorded at site MM with a mean loss of ~2%. For 12 sites, the mean percent gain was always higher than the mean percent loss, except for site SP, which had a ~9% loss and an ~8% gain.

In the ring buffer analysis, we do not see apparent trends in forest cover loss and gain concerning the percent forest cover already present. For example, the two treatment sites with the highest mean percent loss in cover also experienced relatively high cover gains within nine years. Sites BB and SC (Table 5) experienced the most significant mean percent loss but similarly experienced high forest gain levels. The same can be said for areas that experienced the highest mean percent gain across the nine years.

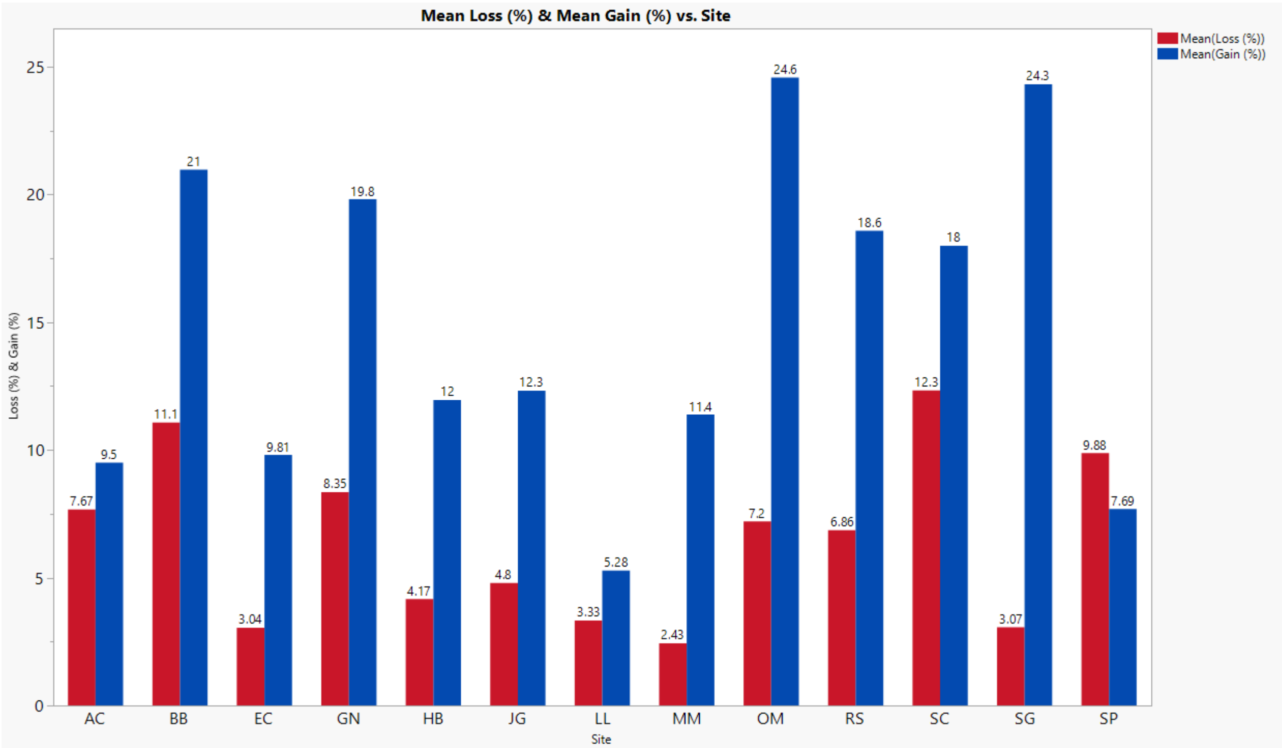

Figure 21 The percent gain and loss by each site.

Table 5 Cover distribution by site showing mean percentages of the three treatments.

Site	% Cover	% Gain	% Loss	% No Cover
AC	44.65	9.5	7.67	38.18
BB	23.98	20.98	11.08	43.97
EC	39.77	9.81	3.04	47.38
GN	38.61	19.81	8.35	33.22
HB	18.55	11.96	4.17	65.33
JG	64.15	12.32	4.8	18.73
LL	40.72	5.28	3.33	50.66
MM	75.41	11.38	2.43	10.77
OM	20.4	24.58	7.2	47.81
RS	34.65	18.58	6.86	39.91
SC	25.75	17.99	12.33	43.92
SG	13.58	24.32	3.07	59.04
SP	42.15	7.69	9.88	40.27

4.3. Regression Analysis

A multiple linear regression was conducted using JMP software. A multiple linear regression is used to the relationship between a response variable and explanatory variables. The response, the gain in forest cover, must be a continuous variable, and the explanatory variables can either be continuous or categorical. The explanatory variables mean slope, mean aspect, mean elevation, and distance to the geometric center was used as continuous explanatory variables within a 30 x 30-meter grid cell. A total of 1807 observations were sampled between 13 sites, 139 observations per site. The response variable, forest cover gain, was calculated as the percent gain in forest cover within a 30 x 30-meter grid. The multiple linear regression explored the relationship between predictor and response variables within a 200-meter distance around the restoration sites. Table 6 shows the variations in the forest cover gain and topographic variables between the thirteen sites.

Table 6 The variations in percent forest cover gain, elevation, aspect, and slope between the thirteen sites within a 200-meter buffer. The negative values for aspect represent south-facing slopes with -1 being the most south-facing. Positive values for aspects represent more north-facing slopes with values closer to 1 facing the most north.

Site	Gain %	Elevation (m)		Aspect		Slope %	
		Min	Max	Min	Max	Min	Max
AC	13.1	1277.11	1458.72	-0.98	0.85	2.11	135.41
BB	29.3	1212.85	1316.19	-0.97	0.92	9.31	91.64
EC	18.9	1151.49	1178.90	-0.92	0.96	0.18	45.32
GN	21.4	1142.14	1194.11	-0.86	1.00	1.44	63.27
HB	16.3	1087.97	1118.73	-0.99	0.93	3.08	42.51
JG	5.8	1145.58	1208.47	-0.52	0.99	4.66	57.90
LL	2.8	1131.27	1159.10	-0.90	0.96	1.21	43.80
MM	11.0	1041.75	1141.26	-0.79	0.98	1.21	56.61
OM	36.0	1109.60	1148.60	-0.97	0.77	0.74	60.86
RS	23.7	1165.01	1241.42	-0.96	0.96	1.47	67.04
SC	24.4	1083.48	1158.47	-0.91	0.93	6.14	75.98
SG	30.0	1090.88	1145.83	-0.95	0.85	2.18	61.27
SP	10.7	1266.08	1354.87	-0.98	0.97	3.60	82.07

The model began with the four predictor variables, and then a backward stepwise regression approach was used to eliminate variables with no significant effects on the response ($P > 0.05$). Of the four variables, only elevation, aspect, and distance were kept in the final model; the mean slope showed no significance and was removed ($P > 0.05$). Distance to the site's center, mean elevation and mean aspect all had a statistically significant impact on the percent gain in forest cover (Table 6). The coefficient summary shows that for every single unit of change in coefficients, there is a minimal, although significant, change in forest cover gain. For the distance variable, moving away from the center of the site tends to result in a decrease in forest cover gain, suggesting that forest cover gain is higher at distances closer to the center of the site. Likewise, for elevation, an increase in elevation results in a decrease in forest cover gain. Also, as the aspect becomes more north-facing, the percent gain decreases.

Table 7 Coefficients Summary

Variables	**Coefficient**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	0.6554085	0.083712	7.83	<.0001*
Distance	-0.000899	0.000131	-6.87	<.0001*
Elevation Mean	-0.000308	7.012e-5	-4.39	<.0001*
Slope Mean	0.0002194	0.000361	0.61	0.5436
Aspect Mean	-0.030849	0.011133	-2.77	0.0056*

The results of the regression show that the coefficient of determination, or the adjusted R Square, had a value of 0.036, indicating that the independent variables explain approximately 3% of the variability in percent forest gain.

Table 8 R Square values

R Square	0.038453
R Square Adjusted	0.036318
Root Mean Square Error	0.260242
Mean of Response	0.17746
Observations	1807

The model did not satisfy all the assumptions of a multiple linear regression needed to validate whether the data were appropriate for the statistic. The Durbin Watson statistic test, which is used to look for autocorrelation in the residuals, had a low value ($d = 0.4868$), indicating a strong positive autocorrelation between variables (a value close to 2 suggests no autocorrelation). Additionally, the significant p-value of 0.001 associated with the Durbin Watson test allows us to reject the null hypothesis and further support that there is a first-order positive autocorrelation. Another assumption was that of independent observations. The model met this assumption as all the observations in the data sampling were independent of each other, and no location was sampled twice. Additionally, there was normality in the distribution of the data among the variables tested. The model also looked for linearity, analyzing whether certain variables had a positive or negative linear effect on the amount of forest cover gained in an area.

Chapter 5 Discussion and Conclusion

This chapter discusses the findings, methodology, and implications of this study. The study had three main goals:

1. Quantify forest cover change for two time periods and assess the overall changes.
2. Analyze and establish baseline data of cover change surrounding the treatment plots.
3. Understand the relationship that slope, elevation, aspect, and distance from the site have on forest cover change using regression analysis.

5.1. Forest Change Cover

The study was successful in quantifying the changes in forest cover between the two time periods. Conducting forest cover analysis with aerial imagery is more advantageous when working with larger-scale studies as field checking methods are much more difficult. In restoration studies, general forest cover metrics can be extracted, such as rate of change and forest structure. For example, we can study how the cover surrounding restoration regions is changing and understand the effect, if any, that it has restoration outcomes.

The overall changes suggest that this region, like the rest of Costa Rica, experienced increases in forested areas between 2005 and 2014. Algeet-Abarquero et al. (2015) found that f. Still, the study region is dominated by the unforested land cover (~56% no forest cover). In comparison to the entire state of Costa Rica, which in 2010 was composed of 51% forest cover, the study region near LCBS has less forest cover (approximately 44%) since 2014. However, this study only analyzed the changes between two time periods and did not consider the year-to-year variations in forest cover. A more accurate rate of reforestation can be attained if multiple years were analyzed instead. As high-resolution aerial imagery becomes more easily accessible, future analysis can continue to quantify forest cover change over more extended periods and at multiple intervals. Forest cover analyses provide useful information on the distribution of cover and serve to estimate ecosystem services, such as carbon sequestration.

Quantifying forest cover through field methods is impractical when working at larger scales. Even at the local scale, such as evaluating the forest cover at each restoration site, in situ methods are difficult to repeat on an annual basis. High-resolution imagery can produce sensible estimates of forest cover and allow us to track changes throughout many years. This consideration is especially important when considering that forest cover studies need to be monitored across large temporal scales to evaluate long-term effects better.

When analyzing forest cover change through digitized imagery, it is essential to maintain the same resolution across several different years to reduce error and improve accuracy in the analysis. Although, conducting forest cover analysis of consecutive years through is likely to be more difficult when working with aerial imagery, as it might be challenging to quantify slight pixel variations. Likewise, conducting an accurate temporal analysis of forest cover change is dependent on the scale. For example, assessing forest cover change through digital imagery would be more accurate when working at larger scales since one is more likely to generalize cover when working with a reduced resolution in the digitization process.

Additionally, when using the whole pixel classification of “cover” and “no cover” used in the study, some areas are probably misrepresented, especially in more heterogeneous regions. Other methodologies exist, however, that address this problem. Subpixel classification allows one to estimate the percent canopy for each pixel as a number between 0 and 100 (Zhu 1994). Forest cover change with subpixel classification is still possible and would allow for more classifications of cover. Likewise, this methodology would better represent actual forest cover and detect changes at a finer scale.

Other methods to quantify and study forest cover changes, such as using LIDAR, can significantly improve forest cover detection (Walton, Nowak, and Greenfield 2008, although they can be costly and inaccessible in some regions (Zahawi et al. 2015). Unlike LIDAR technology, estimating cover change through aerial imagery is relatively inexpensive and accurate (Walton, Nowak, and Greenfield 2008). Additionally, LIDAR can accurately measure canopy height. Horizontal cover growth studies, such as done in this paper, do not take into consideration the height of the canopy. Future studies can incorporate canopy height as a variable to explain the variation in restoration outcomes.

5.2. Multiple Ring Buffer

The multiple ring buffer analysis provides useful baseline data for future studies investigating the effects of forest cover change. Establishing a rate of forest cover increase for the surrounding areas is essential to understanding the long-term impacts of restoration sites on outer forest cover. For these nine years, we see a mean 15% increase in forest cover area for all sites and a mean 6% loss across all sites.

The multiple ring buffer analysis revealed that the mean percent gain was always more significant than the mean percent loss across all sites, except for site SP, which had a ~9% loss and an ~8% gain. An individual linear regression on this site did not attribute the changes in loss to any of the variables used in this study. This analysis suggests that SP is experiencing a higher loss in forest cover compared to other regions. Future studies could investigate the variables contributing to a higher loss in cover compared to forest cover gain. The mean percent gain shows that a significant amount of forest cover was gained at distances up to 100 meters from the site. Subsequent studies should consider this critical distance as forest cover change does not change drastically at distances beyond 100 meters.

The multiple ring buffer analysis provided each a treatment site with a 9-year forest cover analysis of the surrounding environment (see Appendix I). A future study could analyze multiple years of aerial imagery to see the yearly increase in forest cover for the same region. Similarly, it would be beneficial to examine the forest cover increase per year since the project's inception to get a better timeline of the reforestation rate. This study only assessed the changes between two time periods, which reduces the assumptions we can draw from the data.

5.3. Regression Analysis

The analysis indicated that slope, aspect, elevation, and distance to restoration had a significant effect on forest cover gain; however, they were not able to explain the variability in forest cover gain observed across the thirteen restoration sites. For the linear regression model, the significance of the P-value indicates that we can reject the null hypothesis that the variables did not affect forest cover gain. The low R-squared value suggests that the topographic variables studied are not reliable predictors of whether an area would become forested.

The thirteen restoration sites are separated by a minimum and maximum distance of 0.7 and 8 kilometers, respectively (Zahawi et al. 2013). Similarly, they note that there each site varies in elevation, ranging from a low of 1,060 meters to a high of 1,430 meters above sea level (Zahawi et al. 2013). Likewise, each site has different measures of slope ranging between 5-35 degrees.

The study investigated whether the differences in topography contributed to any forest cover gain at each site. Based on previous research, this study was expected to discover relationships between the increase in forest cover gain and certain topographic variables. We discovered that there was no strong relationship between the topographic variables. Had we found a relationship between individual variables and increases in forest cover, future studies evaluating the success of the treatment plots at each site could have attributed the outcomes to these variations in topography derived variables. In contrast, the regression analysis did not reveal a strong correlation between increases in forest cover gain and the surrounding environment. The findings of this study, however, are useful to the ongoing research at these sites because we can now deduce that any variations in restoration outcomes at each site are likely not attributed to the variations in the topographic variables in this study.

Although this study was significant in scale, there was likely not enough variation in topographic elements that could result in different rates in forest cover gain. According to the First Law of Geography, things near each other are more related than things further apart. The literature shows that higher elevations are typically associated with higher recovery rates because these regions are more isolated and less affected by disturbances, such as agriculture, due to unsuitability. For elevation, likely, there was not much disparity between minimum and maximum elevation values between the study sites, as there was only about ~ 400-meter difference in elevation. Similarly, the restoration sites were areas that were previously used for agriculture, suggesting that these regions inherently shared similar elevation and slope profiles.

Additionally, this study assessed the influence that distance to the restoration site had changes in forest cover in the surrounding environment. We expected to find that a closer distance to the geometric center of the study would result in a higher percentage of forest cover gain. This assumption was made under the belief that active restoration practices can act as a catalyst for surrounding forest cover growth. This study was able to show a more significant percentage gain in cover in areas closer to the site's primary area of influence, which in this study was taken as the geometric center. One explanation could be that the surrounding forest cover for each of the sites has varying levels of development. For example, some regions are surrounded by significant roads, while others are surrounded entirely by forest cover. The distance to the geometric center was used to assess how the center of the site influenced the external environment. As a recommendation for future studies, the distance variable should be calculated as the shortest distance to the nearest treatment plot, rather than the distance to the geometric center. Measuring the distance of the sample points to the geometric center likely introduced error.

Likewise, we expected to find a positive correlation between northern facing slopes and gain in forest cover since these regions are more conducible to tree growth in the Northern hemisphere. The study found no strong correlations between north-facing slopes and increases in forest cover. Unlike temperate regions that experience more seasonality due to their distance from the equator, Costa Rica experiences less seasonality as tropical areas are characterized by two seasons: summer and winter. Less seasonality and the relative position of the sun in tropical regions can explain why aspect does not have a strong influence on vegetation growth.

Also, despite the variation in aspect, the sun hits tropical regions overhead much more than in the temperate areas in the northern hemisphere. Therefore, solar radiation does not likely vary by aspect. The findings of this study are consistent with this as they show that aspect did not influence the changes in forest cover observed. Future studies in the study region can assume that aspect has very little influence on forest cover in the tropics. The findings of this study suggest that more complex factors are at play regarding forest cover changes, particularly at restoration sites in areas previously used for agriculture.

Other considerations for subsequent studies should also assess the biodiversity in the surrounding regions through more complex datasets. For example, how do reforestation rates compare when looking at regions near the old growth forest against secondary forests. Old-growth forests are less disturbed regions and contain much lower levels of human disturbance.

Reid et al. 2018 used aerial photography to evaluate the persistence of secondary forest cover in Costa Rica and found that larger forest fragments and proximity to rivers were strong predictors of whether forest regions persisted over 54 years. If proximity to rivers is a strong predictor of forest persistence, then we might find forest cover gain to be more strongly correlated with nearer distances to the river. Correspondingly, we might forest cover loss to be more strongly correlated with treatment sites being a further distance from rivers.

There were many other essential variables this study did not consider. For example, some sites were surrounded by roads and developed lands, areas where forest cover will not change regardless of the influence that the restoration site. Other studies can consider how distance to the nearest road or building affects the changes in forest cover observed at each site. Based on the low adjusted R-square value, there are many unexplored variables that can be contributing to the variation in forest cover gain at each study site.

5.4. Conclusion

This study aimed to evaluate the changes in forest cover surrounding restoration sites at Las Cruces Biological Reserve. Ongoing research at this facility is relevant because it holds some of Costa Rica's last remaining old-growth forest. This study's scope was to evaluate landscape-level changes, which is difficult because accessibility to finer datasets, such as LIDAR, is expensive in remote regions. Aerial imagery provides an inexpensive alternative to assess forest cover changes but provides minimal information on the context of these changes.

The findings of this study provide useful information for this study. The restoration treatment sites were initiated in regions with varying degrees of aspect, slope, and elevation;

however, this study did could not strongly attribute the observed changes to these variables. Although the study did not reveal any correlation between landscape-level elements, quantifying forest cover, and creating baseline data, future studies can still incorporate these elements as it can be essential to the overall understanding of forest cover changes.

Future studies can evaluate performance metrics against baseline data to uncover whether initial forest cover had any long-term effects on the restoration outcomes. Although the data suggest a weak correlation between topographic variables, the study limited the explanation of forest cover changes to topographic variables. Subsequent studies can use other variables, such as distance to the nearest river, as other studies have shown the persistence of forest cover near riparian regions (Reid et al. 2018).

Although the multiple-ring study did not see any trend of increasing forest cover in regions with high forest cover, this study did not consider the patch size instead of focusing on the percent cover within a region. Previous studies have demonstrated how patch size strongly affects the recovery rate (Holl et al. 2017). A consequent analysis could assess the degree of connectivity in forest cover and see whether the patch size correlates with the changes observed.

The measurement of landscape patterns and structure is becoming more easily calculated with advances in data collection and software. Land managers can assess and monitor landscape patterns and the effects they have on the ecological processes. FRAGSTATS is a program that is used to quantify landscape structures from remotely sense data and can assess landscape-level elements such as size, shape, connectivity, and diversity. The data obtained from FRAGSTATS is also used in correlation analysis in large scale studies (Kupfer 2012). Future studies can assess the landscape metrics and their influence on restoration outcomes, particularly in regions surrounding restoration sites. For example, landscape metrics regarding connectivity can be measured and used in future studies to assess their effect on the gain in forest cover for areas surrounding restoration sites, helping landscape managers understand the importance of landscape connectivity within the context of ecological restoration efforts.

The development of effective restoration practices will require researchers to understand further the elements contributing to forest regeneration. Through active restoration practices, land managers can alter the ecological trajectory of pasture lands into those closely resembling natural succession. Understanding the landscape context to evaluate the efficacy of restoration strategies is essential to understanding how regeneration behaves in shifting landscapes. This study attempted to uncover whether the changes in the surrounding landscape could be attributed to variations in topographic variables surrounding the restoration sites. The implications of this study suggest that slope, elevation, aspect, and distance to restoration sites are not reliable predictors on whether areas reforested. Also, we can suggest that the variations in restoration outcomes, specifically relating to forest cover growth, are not like influenced by the variations in topographic variables at each of the restoration sites.

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Appendix I

Ring Buffer Data

Site	Treatment	Distance (m)	Cover (m)	Cover %	Gain m	Gain %	Loss m	Loss %	NoCover m	No Cover %	Total Area m
AC	C	50	7771.1	46.2	1929.4	11.5	420.2	2.5	6691.6	39.8	16812.3
		100	19470.7	59.9	6111.2	18.8	469.5	1.4	6457.9	19.9	32509.3
		150	35069.2	72.7	3231.2	6.7	2207.7	4.6	7698.4	16.0	48206.4
		200	42404.4	66.4	2202.6	3.4	6768.3	10.6	12528.3	19.6	63903.6
		300	88152.2	50.4	5186.0	3.0	14005.6	8.0	67554.4	38.6	174898.3
		400	74401.8	31.3	11177.7	4.7	18154.0	7.6	133953.3	56.4	237686.7
		500	94862.2	31.6	23640.0	7.9	33861.6	11.3	148111.3	49.3	300475.1
		600	164846.2	45.4	38417.0	10.6	25130.9	6.9	134869.5	37.1	363263.5
		700	182553.2	42.8	54582.6	12.8	35450.8	8.3	153465.2	36.0	426051.8
		800	205578.4	42.1	56174.8	11.5	35979.0	7.4	191108.0	39.1	488840.2
		900	211549.1	40.0	52428.0	9.9	42718.2	8.1	222571.7	42.1	529267.0
		1000	118965.0	26.6	32977.8	7.4	47876.8	10.7	248005.6	55.4	447825.1
AC	I	50	8611.9	52.8	3727.4	22.9	429.5	2.6	3529.3	21.7	16298.2
		100	20360.6	63.6	4661.3	14.6	1155.8	3.6	5817.6	18.2	31995.2
		150	30139.3	63.2	2920.7	6.1	4635.3	9.7	9996.9	21.0	47692.2
		200	38892.4	61.4	1532.0	2.4	5351.3	8.4	17613.5	27.8	63389.2
		300	76607.9	44.1	6956.9	4.0	15422.4	8.9	74882.1	43.1	173869.3
		400	75144.3	31.8	11979.7	5.1	17931.1	7.6	131602.3	55.6	236657.3
		500	94535.9	31.6	27920.0	9.3	30532.3	10.2	146457.1	48.9	299445.3
		600	165756.7	45.8	55595.0	15.3	24848.5	6.9	116033.1	32.0	362233.2
		700	181809.8	42.8	35375.2	8.3	43421.3	10.2	164414.8	38.7	425021.1
		800	202572.7	41.5	59410.4	12.2	39422.3	8.1	186403.7	38.2	487809.0
		900	221670.5	40.3	46582.4	8.5	49915.0	9.1	232426.2	42.2	550594.1
		1000	121127.0	28.5	38214.9	9.0	32346.0	7.6	232876.3	54.9	424564.2
AC	P	50	7478.9	42.6	5474.4	31.2	234.9	1.3	4351.5	24.8	17539.8
		100	16465.7	49.5	2568.1	7.7	3716.9	11.2	10486.1	31.5	33236.7
		150	25006.8	51.1	1367.4	2.8	4377.1	8.9	18182.4	37.2	48933.7
		200	33363.0	51.6	2069.5	3.2	4141.3	6.4	25056.9	38.8	64630.7
		300	71111.4	40.3	6916.7	3.9	14016.1	7.9	84308.0	47.8	176352.2
		400	85211.9	35.6	11456.4	4.8	17562.4	7.3	124909.3	52.2	239140.1
		500	111960.0	37.1	32658.5	10.8	33597.4	11.1	123712.1	41.0	301928.0
		600	173352.9	47.5	51315.6	14.1	25639.2	7.0	114408.0	31.4	364715.8
		700	172266.0	40.3	37161.1	8.7	37633.8	8.8	180442.7	42.2	427503.6
		800	178521.3	36.4	46381.5	9.5	48074.6	9.8	217314.1	44.3	490291.5
		900	210755.4	38.1	56953.7	10.3	49071.4	8.9	236298.9	42.7	553079.5
		1000	171085.0	34.4	46190.5	9.3	35525.9	7.1	244244.3	49.1	497045.7
BB	C	50	2626.6	14.8	8762.4	49.3	1223.1	6.9	5159.9	29.0	17772.0
		100	7031.5	21.0	9109.6	27.2	4328.0	12.9	12999.8	38.8	33469.0
		150	10151.4	20.6	12498.6	25.4	8063.7	16.4	18452.2	37.5	49166.0
		200	16117.5	24.8	12302.2	19.0	7514.3	11.6	28929.0	44.6	64863.0
		300	27292.1	15.4	32785.9	18.5	22384.3	12.7	94354.6	53.4	176816.9
		400	62973.5	26.3	46117.5	19.2	29106.0	12.1	101407.8	42.3	239604.9
		500	99607.3	32.9	51622.1	17.1	36176.7	12.0	114986.7	38.0	302392.8
		600	84004.5	23.0	57802.7	15.8	42372.1	11.6	181001.6	49.6	365180.8
		700	79446.0	18.6	72845.1	17.0	45274.3	10.6	230403.4	53.8	427968.7
		800	115181.6	23.5	95070.5	19.4	44678.0	9.1	235826.6	48.1	490756.7
		900	186970.2	33.8	89445.5	16.2	51892.9	9.4	225236.1	40.7	553544.7
		1000	211511.4	34.3	94662.0	15.4	61070.4	9.9	249088.7	40.4	616332.5
BB	I	50	4467.6	27.0	6345.0	38.3	1431.1	8.6	4330.3	26.1	16574.0
		100	7126.0	22.1	7715.8	23.9	4550.2	14.1	12878.8	39.9	32270.9
		150	11504.8	24.0	8471.0	17.7	5356.4	11.2	22635.6	47.2	47967.8
		200	10151.6	15.9	10635.5	16.7	8016.4	12.6	34861.2	54.8	63664.7
		300	32571.6	18.7	36812.0	21.1	21468.9	12.3	83567.4	47.9	174419.9
		400	50729.4	21.4	43664.4	18.4	27635.5	11.7	115178.1	48.6	237207.4
		500	103836.3	34.6	51914.4	17.3	39482.3	13.2	104762.0	34.9	299995.0
		600	94222.7	26.0	57301.0	15.8	37388.2	10.3	173870.6	47.9	362782.5
		700	79395.2	18.7	73522.2	17.3	49058.4	11.5	223594.1	52.5	425570.0
		800	110005.0	22.5	79509.4	16.3	55526.5	11.4	243316.6	49.8	488357.5
		900	167235.2	30.3	92342.6	16.8	46215.2	8.4	245352.1	44.5	551145.0
		1000	196604.5	32.0	91055.2	14.8	57718.9	9.4	268553.8	43.7	613932.4
BB	P	50	2950.3	16.6	5015.4	28.2	2252.2	12.7	7579.5	42.6	17797.4
		100	3330.6	9.9	11971.4	35.7	2298.7	6.9	15893.7	47.5	33494.4

Site	Treatment	Distance (m)	Cover (m)	Cover %	Gain m	Gain %	Loss m	Loss %	NoCover m	No Cover %	Total Area m
		150	13547.5	27.5	13313.3	27.1	4784.6	9.7	17546.1	35.7	49191.5
		200	9267.5	14.3	16763.0	25.8	7405.7	11.4	31452.3	48.5	64888.5
		300	42711.6	24.1	35692.9	20.2	21891.1	12.4	76572.4	43.3	176868.1
		400	56034.9	23.4	42050.9	17.5	34383.4	14.3	107187.1	44.7	239656.3
		500	97905.4	32.4	46226.1	15.3	36421.2	12.0	121891.7	40.3	302444.4
		600	76764.3	21.0	70525.9	19.3	45786.8	12.5	172155.6	47.1	365232.6
		700	78927.1	18.4	75708.0	17.7	41804.3	9.8	231581.3	54.1	428020.7
		800	112318.7	22.9	97635.4	19.9	39720.1	8.1	241134.8	49.1	490808.9
		900	210881.7	38.1	98027.6	17.7	57981.5	10.5	186706.3	33.7	553597.1
		1000	199292.4	32.3	103886.4	16.9	53666.8	8.7	259539.4	42.1	616385.1
EC	C	50	9835.0	56.8	4637.9	26.8	289.2	1.7	2540.2	14.7	17302.3
		100	21956.9	66.5	5566.8	16.9	426.9	1.3	5048.8	15.3	32999.4
		150	28959.4	59.5	9648.0	19.8	579.8	1.2	9509.2	19.5	48696.4
		200	44395.8	68.9	6442.7	10.0	1228.7	1.9	12326.3	19.1	64393.5
		300	96207.0	54.7	13526.0	7.7	3478.4	2.0	62666.7	35.6	175878.1
		400	81086.3	34.0	7251.9	3.0	5026.6	2.1	145301.5	60.9	238666.4
		500	96931.2	32.2	9661.1	3.2	5776.9	1.9	189085.5	62.7	301454.6
		600	100127.4	27.5	12898.5	3.5	12515.4	3.4	238701.5	65.5	364242.9
		700	116855.3	27.4	16939.7	4.0	24279.7	5.7	268956.4	63.0	427031.1
		800	135661.1	27.7	23570.6	4.8	15599.0	3.2	314988.7	64.3	489819.4
		900	120527.7	21.8	42407.8	7.7	26037.5	4.7	363634.7	65.8	552607.6
		1000	128214.4	20.8	51535.0	8.4	35969.5	5.8	399676.7	64.9	615395.7
EC	I	50	6186.7	35.1	5625.0	31.9	360.6	2.0	5448.0	30.9	17620.4
		100	19418.5	58.3	9784.8	29.4	484.7	1.5	3629.4	10.9	33317.4
		150	39982.5	81.6	7507.3	15.3	246.1	0.5	1278.5	2.6	49014.4
		200	49986.0	77.2	3923.8	6.1	926.2	1.4	9875.5	15.3	64711.4
		300	85369.7	48.4	11039.3	6.3	4247.6	2.4	75857.2	43.0	176513.8
		400	86558.0	36.2	7589.0	3.2	4867.2	2.0	140287.7	58.6	239301.9
		500	100406.5	33.2	11758.4	3.9	6272.1	2.1	183652.8	60.8	302089.9
		600	100004.8	27.4	14343.1	3.9	7413.2	2.0	243116.8	66.6	364878.0
		700	107588.6	25.2	19207.3	4.5	27837.9	6.5	273032.2	63.8	427665.9
		800	122653.1	25.0	28640.1	5.8	17867.9	3.6	321292.9	65.5	490454.0
		900	122101.4	22.1	46489.5	8.4	28628.2	5.2	356023.0	64.4	553242.1
		1000	124925.7	20.3	49512.8	8.0	39680.5	6.4	401911.0	65.2	616030.0
EC	P	50	9402.4	53.3	5948.9	33.7	248.5	1.4	2027.6	11.5	17627.4
		100	23144.0	69.5	2556.7	7.7	896.1	2.7	6727.6	20.2	33324.4
		150	25697.5	52.4	5710.3	11.6	1181.7	2.4	16431.9	33.5	49021.5
		200	24772.5	38.3	6958.8	10.8	1277.7	2.0	31709.6	49.0	64718.6
		300	64690.9	36.6	11016.8	6.2	3844.6	2.2	96975.9	54.9	176528.2
		400	79457.7	33.2	14600.8	6.1	5328.0	2.2	139930.0	58.5	239316.5
		500	92401.4	30.6	11093.1	3.7	18600.3	6.2	180009.9	59.6	302104.8
		600	105973.3	29.0	16698.6	4.6	15233.6	4.2	226987.5	62.2	364893.0
		700	120256.9	28.1	17793.3	4.2	13227.2	3.1	276403.8	64.6	427681.2
		800	111685.7	22.8	26187.5	5.3	19199.2	3.9	333397.0	68.0	490469.5
		900	132464.7	24.0	43546.5	7.9	23590.3	4.3	353331.1	63.9	552932.6
		1000	149523.7	26.3	49508.5	8.7	24317.7	4.3	344412.0	60.7	567762.0
GN	C	50	8710.4	50.5	3721.2	21.6	1572.5	9.1	3236.2	18.8	17240.3
		100	15952.7	48.4	8693.4	26.4	2724.3	8.3	5566.9	16.9	32937.3
		150	20445.1	42.0	10577.8	21.7	6180.7	12.7	11430.7	23.5	48634.3
		200	26103.8	40.6	12455.8	19.4	5987.0	9.3	19784.8	30.8	64331.3
		300	63855.3	36.3	39178.7	22.3	14438.8	8.2	58280.7	33.2	175753.5
		400	66307.0	27.8	45716.3	19.2	17706.5	7.4	108811.6	45.6	238541.5
		500	108916.9	36.1	65902.3	21.9	19280.0	6.4	107230.1	35.6	301329.4
		600	126522.9	34.7	83223.7	22.9	29458.1	8.1	124912.7	34.3	364117.4
		700	119167.4	27.9	92776.2	21.7	33944.4	8.0	181017.4	42.4	426905.3
		800	178245.2	36.4	84621.3	17.3	39009.7	8.0	187817.0	38.4	489693.2
		900	225818.5	40.9	80742.2	14.6	42509.2	7.7	203411.4	36.8	552481.3
		1000	260419.0	42.3	75551.2	12.3	46735.7	7.6	232563.1	37.8	615269.0
GN	I	50	9136.6	52.6	1801.2	10.4	1968.1	11.3	4452.4	25.6	17358.3
		100	18408.8	55.7	7583.5	22.9	3037.1	9.2	4025.9	12.2	33055.2
		150	18286.7	37.5	11099.5	22.8	5955.2	12.2	13410.9	27.5	48752.2
		200	20702.1	32.1	15554.0	24.1	5781.0	9.0	22412.2	34.8	64449.3
		300	72516.8	41.2	37189.6	21.1	12787.8	7.3	53495.1	30.4	175989.4
		400	78111.3	32.7	45067.6	18.9	14926.9	6.3	100671.6	42.2	238777.4
		500	108560.8	36.0	65940.1	21.9	20856.2	6.9	106208.3	35.2	301565.4
		600	130389.1	35.8	78126.2	21.4	30788.6	8.5	125049.4	34.3	364353.3
		700	124830.5	29.2	101374.4	23.7	31661.4	7.4	169275.0	39.6	427141.3

Site	Treatment	Distance (m)	Cover (m)	Cover %	Gain m	Gain %	Loss m	Loss %	NoCover m	No Cover %	Total Area m
		800	187946.4	38.4	75844.7	15.5	41023.3	8.4	185114.9	37.8	489929.3
		900	235208.7	42.6	76390.1	13.8	42156.1	7.6	198962.3	36.0	552717.2
		1000	243354.2	39.5	79785.3	13.0	47603.1	7.7	244762.5	39.8	615505.1
GN	P	50	4660.6	26.6	6982.1	39.8	1342.7	7.7	4558.1	26.0	17543.5
		100	18508.9	55.7	4278.3	12.9	2881.0	8.7	7572.0	22.8	33240.3
		150	23983.6	49.0	8344.8	17.1	3873.0	7.9	12735.7	26.0	48937.1
		200	28926.7	44.8	11342.4	17.5	6657.8	10.3	17707.0	27.4	64634.0
		300	48004.1	27.2	39793.6	22.6	17440.9	9.9	71119.7	40.3	176358.3
		400	64398.9	26.9	64694.7	27.1	19061.7	8.0	90990.4	38.0	239145.6
		500	117031.6	38.8	60598.9	20.1	19845.9	6.6	104456.3	34.6	301932.9
		600	128560.2	35.2	79908.1	21.9	31376.1	8.6	124875.7	34.2	364720.1
		700	126791.2	29.7	80321.9	18.8	36472.5	8.5	183921.8	43.0	427507.4
		800	180979.5	36.9	78859.9	16.1	33041.8	6.7	197413.4	40.3	490294.6
		900	207876.9	37.6	88214.1	15.9	42887.7	7.8	214103.2	38.7	553081.9
		1000	273157.3	44.4	79106.5	12.8	45899.3	7.5	217706.0	35.3	615869.0
HB	C	50	2148.9	12.4	4045.0	23.4	456.5	2.6	10657.1	61.6	17307.3
		100	4594.3	13.9	7114.2	21.6	1098.9	3.3	20196.9	61.2	33004.3
		150	6259.9	12.9	6065.8	12.5	2645.9	5.4	33729.6	69.3	48701.2
		200	9281.7	14.4	5269.0	8.2	3057.0	4.7	46790.5	72.7	64398.2
		300	26167.3	14.9	27452.7	15.6	8486.3	4.8	113780.8	64.7	175887.0
		400	51198.6	21.5	34275.6	14.4	12649.7	5.3	140550.9	58.9	238674.8
		500	86850.2	28.8	35063.2	11.6	15427.0	5.1	164122.1	54.4	301462.5
		600	98822.3	27.1	43668.1	12.0	16245.7	4.5	205514.1	56.4	364250.2
		700	92359.5	21.6	37921.3	8.9	12788.4	3.0	283968.7	66.5	427037.9
		800	107676.0	22.0	40699.7	8.3	17557.0	3.6	323893.0	66.1	489825.6
		900	110036.2	19.9	42029.5	7.6	21113.8	3.8	379433.9	68.7	552613.4
		1000	120104.0	19.5	38977.3	6.3	25851.0	4.2	430468.7	69.9	615401.0
HB	I	50	2017.8	11.6	4521.6	26.0	282.2	1.6	10588.8	60.8	17410.4
		100	5532.7	16.7	3875.7	11.7	1157.0	3.5	22542.1	68.1	33107.5
		150	4757.1	9.7	5108.1	10.5	1795.6	3.7	37143.7	76.1	48804.5
		200	9233.9	14.3	6426.9	10.0	3480.2	5.4	45360.6	70.3	64501.6
		300	23078.5	13.1	27773.4	15.8	8667.0	4.9	116575.4	66.2	176094.3
		400	50276.2	21.0	29079.4	12.2	9536.1	4.0	149990.8	62.8	238882.6
		500	75369.1	25.0	30891.9	10.2	17426.9	5.8	177982.9	59.0	301670.8
		600	93720.0	25.7	40967.6	11.2	18093.1	5.0	211678.4	58.1	364459.1
		700	91022.9	21.3	45470.7	10.6	13458.1	3.1	277295.6	64.9	427247.3
		800	107236.4	21.9	41727.1	8.5	15370.1	3.1	325702.0	66.5	490035.5
		900	121409.9	22.0	46060.3	8.3	22906.6	4.1	362447.0	65.6	552823.8
		1000	107771.8	17.5	38776.0	6.3	27069.5	4.4	441994.7	71.8	615611.9
HB	P	50	1128.4	6.5	2125.3	12.2	634.5	3.6	13579.5	77.7	17467.7
		100	2683.1	8.1	6080.7	18.3	867.0	2.6	23534.0	71.0	33164.8
		150	7806.1	16.0	5647.8	11.6	2605.7	5.3	32802.2	67.1	48861.8
		200	7514.1	11.6	8046.2	12.5	3565.9	5.5	45432.6	70.4	64558.8
		300	34065.6	19.3	22280.4	12.6	8310.7	4.7	111551.9	63.3	176208.6
		400	51876.3	21.7	38471.0	16.1	11378.6	4.8	137270.7	57.4	238996.7
		500	80665.2	26.7	37865.4	12.5	16458.9	5.5	166795.2	55.3	301784.7
		600	93582.4	25.7	43172.2	11.8	17053.8	4.7	210764.4	57.8	364572.8
		700	99084.5	23.2	37456.2	8.8	12431.6	2.9	278388.4	65.1	427360.8
		800	105398.9	21.5	42105.2	8.6	15521.7	3.2	327123.2	66.7	490148.9
		900	113614.4	20.5	44187.7	8.0	19583.4	3.5	375551.4	67.9	552937.0
		1000	112124.5	18.2	35775.2	5.8	27936.9	4.5	439888.3	71.4	615724.9
JG	C	50	17370.7	99.5	78.4	0.4	6.9	0.0	0.0	0.0	17456.0
		100	29321.7	88.4	967.5	2.9	1380.8	4.2	1483.1	4.5	33153.1
		150	37027.4	75.8	3577.3	7.3	1837.5	3.8	6408.0	13.1	48850.1
		200	45260.0	70.1	4966.3	7.7	1973.1	3.1	12347.8	19.1	64547.2
		300	115307.1	65.4	17467.2	9.9	11676.4	6.6	31734.6	18.0	176185.4
		400	138387.9	57.9	33151.5	13.9	16212.7	6.8	51221.4	21.4	238973.6
		500	167972.0	55.7	55509.9	18.4	16536.3	5.5	61743.5	20.5	301761.7
		600	187905.3	51.5	65899.8	18.1	18923.1	5.2	91821.7	25.2	364549.9
		700	220499.3	51.6	76619.6	17.9	20389.6	4.8	109829.5	25.7	427338.0
		800	277544.9	56.6	79025.2	16.1	23219.8	4.7	110336.3	22.5	490126.2
		900	341233.8	61.7	82849.0	15.0	25208.4	4.6	103623.3	18.7	552914.4
		1000	366168.1	59.5	91090.3	14.8	31899.3	5.2	126544.7	20.6	615702.4
JG	I	50	15893.1	94.3	616.5	3.7	114.0	0.7	237.3	1.4	16860.9
		100	24388.7	74.9	1829.3	5.6	934.0	2.9	5405.9	16.6	32557.9
		150	33969.1	70.4	3638.2	7.5	2239.0	4.6	8408.5	17.4	48254.9
		200	46357.4	72.5	7274.0	11.4	2496.9	3.9	7823.6	12.2	63951.9

Site	Treatment	Distance (m)	Cover (m)	Cover %	Gain m	Gain %	Loss m	Loss %	NoCover m	No Cover %	Total Area m
		300	114284.9	65.3	16639.3	9.5	8385.3	4.8	35685.1	20.4	174994.6
		400	155784.3	65.5	23480.2	9.9	15245.6	6.4	43272.4	18.2	237782.5
		500	174365.9	58.0	52401.8	17.4	14417.1	4.8	59385.6	19.8	300570.4
		600	197345.7	54.3	64949.1	17.9	20312.5	5.6	80750.9	22.2	363358.3
		700	215557.6	50.6	78901.8	18.5	24172.2	5.7	107514.5	25.2	426146.1
		800	255691.1	52.3	85160.8	17.4	24101.3	4.9	123980.8	25.4	488934.0
		900	343116.9	62.2	82718.7	15.0	24853.6	4.5	101032.7	18.3	551721.9
		1000	356136.1	58.0	89013.4	14.5	28517.9	4.6	140842.2	22.9	614509.7
JG	P	50	15204.0	85.1	179.3	1.0	1434.9	8.0	1042.2	5.8	17860.4
		100	26100.1	77.8	3249.0	9.7	1420.5	4.2	2787.9	8.3	33557.4
		150	31399.4	63.7	4664.3	9.5	1145.6	2.3	12045.0	24.5	49254.4
		200	41318.8	63.6	5735.6	8.8	4912.6	7.6	12984.4	20.0	64951.4
		300	103269.1	58.3	20471.5	11.6	9367.7	5.3	43885.3	24.8	176993.7
		400	131441.7	54.8	41054.5	17.1	15808.0	6.6	51477.5	21.5	239781.6
		500	173458.5	57.3	49939.1	16.5	18161.4	6.0	61010.7	20.2	302569.6
		600	185566.3	50.8	53460.4	14.6	18406.6	5.0	107924.2	29.5	365357.5
		700	226776.2	53.0	65586.5	15.3	22265.4	5.2	113517.4	26.5	428145.4
		800	272379.4	55.5	84031.4	17.1	25642.2	5.2	108880.2	22.2	490933.3
		900	327672.7	59.2	94957.0	17.1	23075.8	4.2	108015.8	19.5	553721.3
		1000	358704.0	58.2	89612.0	14.5	32740.4	5.3	135452.7	22.0	616509.1
LL	C	50	7849.4	45.1	512.3	2.9	412.1	2.4	8644.8	49.6	17418.7
		100	22589.5	68.2	630.7	1.9	244.5	0.7	9650.9	29.1	33115.7
		150	32198.1	66.0	778.1	1.6	694.0	1.4	15142.3	31.0	48812.6
		200	41351.4	64.1	1673.6	2.6	892.1	1.4	20592.6	31.9	64509.6
		300	86296.9	49.0	9284.3	5.3	5664.1	3.2	74864.6	42.5	176109.9
		400	110575.2	46.3	12422.1	5.2	16389.0	6.9	99511.5	41.7	238897.7
		500	124421.1	41.2	19519.1	6.5	15233.7	5.0	142511.6	47.2	301685.5
		600	113732.0	31.2	18430.7	5.1	9608.2	2.6	222702.4	61.1	364473.3
		700	161307.6	37.8	31265.3	7.3	10080.4	2.4	224607.8	52.6	427261.0
		800	157685.6	32.2	37438.0	7.6	15661.9	3.2	279263.4	57.0	490048.9
		900	97457.6	17.6	41868.8	7.6	17659.3	3.2	395851.0	71.6	552836.7
		1000	103145.9	16.8	54736.4	8.9	28804.7	4.7	428937.3	69.7	615624.3
LL	I	50	6337.3	34.0	337.0	1.8	254.0	1.4	11702.5	62.8	18630.8
		100	16258.4	47.5	1232.3	3.6	806.4	2.4	15900.6	46.5	34197.6
		150	26403.8	52.9	981.1	2.0	984.3	2.0	21502.1	43.1	49871.3
		200	40219.1	61.3	2508.4	3.8	1278.7	2.0	21551.5	32.9	65557.7
		300	104657.3	58.7	8470.3	4.8	13170.2	7.4	51894.5	29.1	178192.3
		400	111264.0	46.2	8688.3	3.6	15418.9	6.4	105603.6	43.8	240974.7
		500	111208.3	36.6	18163.7	6.0	10042.5	3.3	164347.4	54.1	303761.8
		600	123536.5	33.7	19829.3	5.4	9254.1	2.5	213927.9	58.4	366547.8
		700	194297.5	45.3	28561.3	6.7	8487.4	2.0	197988.9	46.1	429335.2
		800	140749.3	28.6	38929.6	7.9	12921.6	2.6	299522.5	60.9	492123.0
		900	88923.9	16.0	42649.0	7.7	20963.4	3.8	402374.6	72.5	554911.0
		1000	118821.1	19.2	56954.4	9.2	31873.1	5.2	410050.2	66.4	617698.9
LL	P	50	5209.1	28.9	431.1	2.4	295.0	1.6	12119.4	67.1	18054.6
		100	16880.8	50.3	815.5	2.4	743.6	2.2	15139.4	45.1	33579.4
		150	26746.6	54.3	1549.0	3.1	922.6	1.9	20045.3	40.7	49263.6
		200	39596.0	61.0	2635.4	4.1	1734.8	2.7	20990.9	32.3	64957.2
		300	86035.7	48.6	10351.4	5.8	12565.2	7.1	68050.3	38.4	177002.7
		400	99291.2	41.4	7416.4	3.1	15002.5	6.3	118080.1	49.2	239790.2
		500	120240.0	39.7	14517.1	4.8	11383.7	3.8	156436.4	51.7	302577.2
		600	121631.8	33.3	23666.2	6.5	9318.3	2.6	210748.2	57.7	365364.5
		700	190751.9	44.6	30149.8	7.0	8608.1	2.0	198642.2	46.4	428152.0
		800	158258.4	32.2	45548.5	9.3	14281.5	2.9	272851.2	55.6	490939.6
		900	96039.8	17.3	40967.7	7.4	24225.4	4.4	392494.5	70.9	553727.3
		1000	116534.3	18.9	57389.6	9.3	28784.8	4.7	413806.0	67.1	616514.8
MM	C	50	10330.4	62.4	6235.1	37.6	0.0	0.0	0.0	0.0	16565.6
		100	26277.7	81.4	5984.9	18.6	0.0	0.0	0.0	0.0	32262.6
		150	41806.6	87.2	6153.0	12.8	0.0	0.0	0.0	0.0	47959.6
		200	61121.7	96.0	2534.9	4.0	0.0	0.0	0.0	0.0	63656.7
		300	165614.9	95.0	7749.2	4.4	170.3	0.1	870.0	0.5	174404.3
		400	212184.2	89.5	17594.0	7.4	1780.6	0.8	5633.7	2.4	237192.5
		500	240592.5	80.2	33471.9	11.2	8284.5	2.8	17631.7	5.9	299980.6
		600	285239.8	78.6	46671.8	12.9	2232.1	0.6	28624.9	7.9	362768.7
		700	346441.1	81.4	32997.6	7.8	2987.5	0.7	43130.5	10.1	425556.8
		800	374682.6	76.7	38900.2	8.0	11955.0	2.4	62807.1	12.9	488344.9
		900	405745.2	73.6	43914.2	8.0	8843.1	1.6	92630.5	16.8	551133.0

Site	Treatment	Distance (m)	Cover (m)	Cover %	Gain m	Gain %	Loss m	Loss %	NoCover m	No Cover %	Total Area m
		1000	422994.4	68.9	55629.0	9.1	19405.6	3.2	115892.0	18.9	613921.0
MM	I	50	13400.4	78.6	3554.9	20.9	88.1	0.5	0.0	0.0	17043.5
		100	29580.7	90.3	7.9	0.0	3151.8	9.6	0.0	0.0	32740.4
		150	41369.7	85.4	1113.4	2.3	4230.7	8.7	1723.5	3.6	48437.4
		200	49603.1	77.3	4725.5	7.4	1246.2	1.9	8559.5	13.3	64134.4
		300	123842.2	70.6	17161.0	9.8	2224.5	1.3	32132.0	18.3	175359.6
		400	144227.9	60.6	32218.2	13.5	8029.4	3.4	53672.0	22.5	238147.6
		500	192500.7	64.0	32552.5	10.8	8069.5	2.7	67812.8	22.5	300935.5
		600	233747.6	64.3	51573.7	14.2	8270.0	2.3	70132.1	19.3	363723.4
		700	271401.7	63.6	72239.7	16.9	11969.0	2.8	70900.9	16.6	426511.2
		800	292902.2	59.9	86621.9	17.7	11669.8	2.4	98105.2	20.1	489299.1
		900	391814.0	71.0	74094.0	13.4	11042.9	2.0	75136.1	13.6	552087.0
		1000	470948.8	76.6	49962.0	8.1	20080.1	3.3	73883.9	12.0	614874.8
MM	P	50	13570.3	81.8	3014.3	18.2	0.0	0.0	0.0	0.0	16584.6
		100	31989.1	99.1	0.0	0.0	292.5	0.9	0.0	0.0	32281.6
		150	37798.2	78.8	2942.9	6.1	5581.5	11.6	1656.0	3.5	47978.6
		200	48913.5	76.8	4654.8	7.3	2577.0	4.0	7530.2	11.8	63675.7
		300	129425.1	74.2	20550.7	11.8	1652.6	0.9	22813.9	13.1	174442.3
		400	160203.3	67.5	27758.6	11.7	5981.8	2.5	43286.8	18.2	237230.5
		500	187550.4	62.5	35474.3	11.8	9445.6	3.1	67548.2	22.5	300018.6
		600	235545.9	64.9	46804.7	12.9	7409.2	2.0	73046.9	20.1	362806.7
		700	281696.3	66.2	66626.5	15.7	10578.2	2.5	66693.8	15.7	425594.7
		800	309543.7	63.4	76186.0	15.6	10793.5	2.2	91859.7	18.8	488382.9
		900	392844.3	71.3	73403.7	13.3	11392.1	2.1	73531.0	13.3	551171.0
		1000	461394.7	75.2	53844.0	8.8	16100.9	2.6	82619.4	13.5	613959.0
OM	C	50	1399.8	8.1	10133.9	58.4	767.4	4.4	5054.2	29.1	17355.3
		100	7046.7	21.3	9409.2	28.5	1566.7	4.7	15029.7	45.5	33052.3
		150	10321.7	21.2	11222.1	23.0	4290.6	8.8	22915.0	47.0	48749.4
		200	16275.6	25.3	17917.7	27.8	4568.4	7.1	25684.7	39.9	64446.4
		300	27892.3	15.8	36586.0	20.8	8768.8	5.0	102736.6	58.4	175983.8
		400	32891.4	13.8	56978.0	23.9	18315.0	7.7	130587.6	54.7	238771.9
		500	70124.5	23.3	56343.1	18.7	20393.7	6.8	154698.7	51.3	301560.0
		600	88125.7	24.2	63765.1	17.5	31163.8	8.6	181293.5	49.8	364348.0
		700	97073.9	22.7	83570.6	19.6	37974.1	8.9	208517.5	48.8	427136.1
		800	76787.1	15.7	84101.9	17.2	44077.7	9.0	284957.5	58.2	489924.2
		900	122728.6	22.2	105299.6	19.1	52068.9	9.4	272615.2	49.3	552712.3
		1000	181884.1	29.6	100362.2	16.3	42264.9	6.9	290989.0	47.3	615500.2
OM	I	50	1482.6	8.5	10449.8	60.1	211.4	1.2	5250.3	30.2	17394.0
		100	6661.7	20.1	11331.9	34.2	3340.1	10.1	11757.3	35.5	33091.0
		150	12880.0	26.4	12983.1	26.6	3773.5	7.7	19151.4	39.3	48788.0
		200	12841.7	19.9	16137.9	25.0	2131.8	3.3	33373.6	51.8	64485.0
		300	27930.4	15.9	39351.3	22.4	10822.6	6.1	97956.5	55.6	176060.8
		400	26571.8	11.1	54992.0	23.0	19402.1	8.1	137882.9	57.7	238848.8
		500	62725.5	20.8	61234.1	20.3	26111.3	8.7	151565.8	50.2	301636.7
		600	76570.8	21.0	65904.2	18.1	27452.4	7.5	194497.3	53.4	364424.6
		700	105756.8	24.8	84555.5	19.8	31728.0	7.4	205172.2	48.0	427212.5
		800	95557.5	19.5	91269.6	18.6	41665.9	8.5	261507.4	53.4	490000.4
		900	112296.2	20.3	95835.2	17.3	50790.2	9.2	293866.8	53.2	552788.4
		1000	159125.5	25.8	110500.5	18.0	47212.7	7.7	298737.4	48.5	615576.1
OM	P	50	3491.8	19.9	8992.6	51.1	879.8	5.0	4221.4	24.0	17585.6
		100	8590.2	25.8	9585.6	28.8	1928.9	5.8	13177.9	39.6	33282.5
		150	12214.0	24.9	12345.7	25.2	4059.2	8.3	20360.6	41.6	48979.4
		200	17581.4	27.2	17035.2	26.3	3373.1	5.2	26686.8	41.3	64676.4
		300	22140.0	12.5	43573.7	24.7	9297.3	5.3	101432.6	57.5	176443.6
		400	30303.7	12.7	57970.6	24.2	17809.6	7.4	133147.5	55.7	239231.4
		500	69755.2	23.1	57721.3	19.1	22692.6	7.5	151850.1	50.3	302019.2
		600	81343.9	22.3	63781.5	17.5	26621.6	7.3	193060.0	52.9	364807.0
		700	96885.9	22.7	86698.2	20.3	40466.0	9.5	203544.7	47.6	427594.7
		800	94644.7	19.3	88617.5	18.1	39158.9	8.0	267961.4	54.6	490382.5
		900	108896.3	19.7	99467.6	18.0	51969.3	9.4	292837.1	52.9	553170.3
		1000	168274.4	27.3	107728.4	17.5	48272.9	7.8	291682.2	47.4	615958.0
RS	C	50	8644.4	55.6	6040.8	38.8	99.0	0.6	765.5	4.9	15549.8
		100	20257.3	64.8	2380.8	7.6	854.8	2.7	7753.8	24.8	31246.7
		150	26660.7	56.8	5226.4	11.1	2627.7	5.6	12428.8	26.5	46943.6
		200	30394.8	48.5	12152.9	19.4	6755.3	10.8	13337.5	21.3	62640.5
		300	59836.1	34.7	31345.4	18.2	21404.7	12.4	59785.5	34.7	172371.7
		400	76029.6	32.3	41466.9	17.6	14203.6	6.0	103459.3	44.0	235159.3
		500	93073.7	31.2	44459.9	14.9	22875.1	7.7	137538.3	46.2	297947.0

Site	Treatment	Distance (m)	Cover (m)	Cover %	Gain m	Gain %	Loss m	Loss %	NoCover m	No Cover %	Total Area m
		600	102783.3	28.5	55032.8	15.3	25010.5	6.9	177908.0	49.3	360734.6
		700	103135.6	24.4	73261.0	17.3	45886.3	10.8	201239.3	47.5	423522.2
		800	114950.8	23.6	80757.2	16.6	33217.9	6.8	257384.0	52.9	486309.9
		900	109494.3	19.9	99991.7	18.2	42926.7	7.8	296684.9	54.0	549097.5
		1000	87343.3	14.3	122186.7	20.0	33841.1	5.5	368513.9	60.2	611885.0
RS	I	50	17959.7	62.8	8136.0	28.5	783.9	2.7	1707.4	6.0	28587.1
		100	32118.4	61.8	11574.5	22.3	1762.3	3.4	6495.0	12.5	51950.2
		150	26229.9	41.2	16934.5	26.6	5728.6	9.0	14731.3	23.2	63624.3
		200	26696.1	33.9	15421.7	19.6	10316.3	13.1	26381.1	33.5	78815.1
		300	69681.2	34.1	33235.8	16.3	15936.5	7.8	85420.2	41.8	204273.6
		400	88123.2	33.0	33650.6	12.6	15990.0	6.0	129039.4	48.4	266803.2
		500	103630.5	31.5	43768.4	13.3	24154.6	7.3	157918.1	47.9	329471.6
		600	107338.1	27.4	65668.2	16.7	35962.8	9.2	183222.1	46.7	392191.1
		700	98778.5	21.7	77175.5	17.0	36865.0	8.1	242130.2	53.2	454949.2
		800	106931.2	20.7	91140.5	17.6	38450.7	7.4	281195.2	54.3	517717.6
		900	103868.4	17.9	112978.8	19.5	41400.6	7.1	322239.4	55.5	580487.2
		1000	90865.9	14.1	116837.3	18.2	31372.0	4.9	404186.8	62.8	643262.1
RS	P	50	10478.6	61.2	5522.3	32.2	281.6	1.6	852.3	5.0	17134.8
		100	17971.2	54.7	10198.9	31.1	1297.4	4.0	3364.3	10.2	32831.8
		150	21856.7	45.0	10572.2	21.8	2906.5	6.0	13193.4	27.2	48528.7
		200	26745.5	41.6	15374.0	23.9	5081.3	7.9	17025.0	26.5	64225.8
		300	58576.5	33.4	26309.8	15.0	14744.5	8.4	75911.7	43.2	175542.5
		400	68849.5	28.9	31832.7	13.4	14023.1	5.9	123625.2	51.9	238330.5
		500	100992.2	33.5	29941.0	9.9	18053.2	6.0	152132.0	50.5	301118.5
		600	126996.7	34.9	40527.2	11.1	28756.4	7.9	167626.2	46.1	363906.5
		700	106480.6	25.0	67115.6	15.7	30841.4	7.2	222256.8	52.1	426694.4
		800	96546.5	19.7	83513.1	17.1	40056.6	8.2	269366.2	55.0	489482.4
		900	118664.0	21.5	102329.1	18.5	40837.0	7.4	290440.3	52.6	552270.4
		1000	80484.9	13.1	98489.5	16.0	40434.8	6.6	395649.1	64.3	615058.2
SC	C	50	5900.0	34.4	7342.1	42.8	1122.6	6.5	2805.7	16.3	17170.4
		100	14138.9	43.0	7982.5	24.3	4776.7	14.5	5969.4	18.2	32867.5
		150	18184.4	37.4	11645.2	24.0	9409.6	19.4	9325.4	19.2	48564.5
		200	19772.7	30.8	14446.2	22.5	9801.6	15.3	20241.1	31.5	64261.6
		300	61981.7	35.3	27563.0	15.7	21441.5	12.2	64627.9	36.8	175614.1
		400	43797.4	18.4	23511.1	9.9	57236.3	24.0	113857.4	47.8	238402.2
		500	43582.8	14.5	52576.5	17.5	49583.5	16.5	155447.5	51.6	301190.3
		600	61964.4	17.0	75048.6	20.6	19384.9	5.3	207580.7	57.0	363978.5
		700	95420.7	22.4	62654.0	14.7	28843.7	6.8	239848.1	56.2	426766.5
		800	97914.3	20.0	73867.1	15.1	37675.3	7.7	280098.0	57.2	489554.7
		900	103321.0	18.7	88607.6	16.0	36629.8	6.6	323784.5	58.6	552342.8
		1000	97830.7	15.9	102077.3	16.6	47065.3	7.7	368157.5	59.9	615130.8
SC	I	50	5691.8	33.3	4615.7	27.0	1663.6	9.7	5120.3	30.0	17091.4
		100	15467.1	47.2	9316.4	28.4	3508.4	10.7	4496.5	13.7	32788.4
		150	17137.8	35.3	9048.4	18.7	10635.7	21.9	11663.5	24.1	48485.4
		200	23031.3	35.9	14606.0	22.8	8867.0	13.8	17678.1	27.5	64182.4
		300	49741.6	28.3	24078.1	13.7	34752.8	19.8	66883.2	38.1	175455.8
		400	48675.0	20.4	28427.6	11.9	55275.2	23.2	105866.0	44.4	238243.8
		500	52864.1	17.6	41996.8	14.0	36308.3	12.1	169862.6	56.4	301031.8
		600	52608.3	14.5	68876.2	18.9	22164.0	6.1	220171.4	60.5	363819.8
		700	97256.9	22.8	72241.8	16.9	24350.0	5.7	232759.0	54.6	426607.8
		800	106580.1	21.8	71180.2	14.5	38239.1	7.8	273396.4	55.9	489395.8
		900	89900.3	16.3	85767.5	15.5	36128.7	6.5	340387.3	61.6	552183.8
		1000	93374.5	15.2	93365.7	15.2	43706.3	7.1	384525.2	62.5	614971.7
SC	P	50	6511.8	36.9	2525.1	14.3	4721.9	26.8	3880.8	22.0	17639.7
		100	15458.4	46.4	6495.7	19.5	5516.8	16.5	5865.8	17.6	33336.7
		150	21152.9	43.1	9968.9	20.3	4181.0	8.5	13730.9	28.0	49033.7
		200	17959.9	27.7	12308.7	19.0	10502.1	16.2	23960.1	37.0	64730.7
		300	41197.2	23.3	22570.2	12.8	47007.2	26.6	65778.0	37.3	176552.5
		400	58239.2	24.3	33228.6	13.9	44829.2	18.7	103043.6	43.1	239340.6
		500	51201.8	16.9	40378.4	13.4	30713.9	10.2	179834.6	59.5	302128.7
		600	64904.8	17.8	56738.3	15.5	24959.3	6.8	218314.4	59.8	364916.8
		700	92015.1	21.5	75252.7	17.6	25056.3	5.9	235380.7	55.0	427704.8
		800	104542.1	21.3	69767.0	14.2	36712.1	7.5	279471.9	57.0	490493.0
		900	88420.6	16.0	83641.0	15.1	34322.5	6.2	346896.9	62.7	553281.1
		1000	95511.8	15.5	92525.9	15.0	42659.9	6.9	385371.4	62.6	616069.0
SG	C	50	638.3	3.8	4814.2	28.6	136.3	0.8	11270.3	66.8	16859.1
		100	1166.5	3.6	10571.5	32.5	392.9	1.2	20425.1	62.7	32556.0
		150	3619.4	7.5	13122.8	27.2	674.4	1.4	30836.3	63.9	48252.9

Site	Treatment	Distance (m)	Cover (m)	Cover %	Gain m	Gain %	Loss m	Loss %	NoCover m	No Cover %	Total Area m
		200	11446.0	17.9	18139.0	28.4	910.8	1.4	33454.1	52.3	63949.9
		300	19784.1	11.3	35572.6	20.3	4025.4	2.3	115608.4	66.1	174990.5
		400	18009.9	7.6	43243.0	18.2	5244.7	2.2	171280.6	72.0	237778.2
		500	48463.2	16.1	66821.0	22.2	11705.4	3.9	173576.3	57.7	300565.9
		600	62664.9	17.2	97929.1	27.0	11411.0	3.1	191348.6	52.7	363353.6
		700	63592.6	14.9	94411.7	22.2	15960.8	3.7	252176.1	59.2	426141.2
		800	80766.7	16.5	112913.4	23.1	21529.4	4.4	273719.4	56.0	488928.9
		900	127937.1	23.2	124726.1	22.6	32041.1	5.8	267012.4	48.4	551716.7
		1000	148547.3	24.2	125718.5	20.5	37107.7	6.0	303130.7	49.3	614504.2
SG	I	50	1634.1	9.6	7699.3	45.1	625.5	3.7	7113.0	41.7	17072.0
		100	1986.8	6.1	11059.5	33.8	334.2	1.0	19388.4	59.2	32768.9
		150	1376.4	2.8	10414.3	21.5	205.9	0.4	36469.3	75.2	48465.8
		200	4526.4	7.1	14408.4	22.5	1895.9	3.0	43332.1	67.5	64162.8
		300	25223.8	14.4	44654.9	25.5	5021.1	2.9	100516.6	57.3	175416.3
		400	20231.7	8.5	54424.1	22.8	3256.0	1.4	160292.3	67.3	238204.1
		500	25612.3	8.5	79030.8	26.3	7356.0	2.4	188992.8	62.8	300991.9
		600	58360.9	16.0	90306.2	24.8	12549.8	3.4	202562.8	55.7	363779.7
		700	65273.1	15.3	91758.6	21.5	16833.6	3.9	252702.1	59.2	426567.4
		800	99605.2	20.4	110687.1	22.6	29964.9	6.1	249097.9	50.9	489355.1
		900	95697.7	17.3	125762.4	22.8	26846.7	4.9	303836.1	55.0	552142.9
		1000	140444.0	22.8	130289.5	21.2	39733.2	6.5	304463.9	49.5	614930.6
SG	P	50	0.0	0.0	2961.9	16.6	0.0	0.0	14879.2	83.4	17841.1
		100	2556.7	7.6	10903.3	32.5	309.9	0.9	19768.1	58.9	33538.1
		150	6590.4	13.4	14326.2	29.1	676.2	1.4	27642.3	56.1	49235.1
		200	10048.0	15.5	14184.1	21.8	700.1	1.1	40000.0	61.6	64932.1
		300	15812.2	8.9	36022.6	20.4	2278.3	1.3	122842.0	69.4	176955.1
		400	33466.4	14.0	38076.6	15.9	9014.8	3.8	159185.4	66.4	239743.1
		500	53995.5	17.8	62643.7	20.7	11867.9	3.9	174024.1	57.5	302531.1
		600	59882.9	16.4	94546.2	25.9	12427.8	3.4	198462.2	54.3	365319.1
		700	66665.4	15.6	105670.3	24.7	15810.6	3.7	239960.8	56.1	428107.1
		800	86360.4	17.6	106573.0	21.7	21097.4	4.3	276864.2	56.4	490895.1
		900	125849.4	22.7	120443.9	21.8	33097.0	6.0	274292.9	49.5	553683.2
		1000	164785.3	26.7	132484.7	21.5	29115.1	4.7	290085.8	47.1	616470.9
SP	C	50	187.5	1.1	2637.3	15.0	1029.6	5.8	13762.3	78.1	17616.8
		100	10440.6	31.3	3281.7	9.9	7678.2	23.0	11913.3	35.8	33313.9
		150	17999.7	36.7	3760.4	7.7	7958.7	16.2	19292.1	39.4	49010.9
		200	30368.2	46.9	4497.1	6.9	5008.7	7.7	24834.0	38.4	64708.0
		300	85621.4	48.5	14537.1	8.2	13299.2	7.5	63049.4	35.7	176507.0
		400	124506.8	52.0	20641.1	8.6	23325.8	9.7	70821.6	29.6	239295.3
		500	140356.2	46.5	22728.3	7.5	37661.4	12.5	101337.6	33.5	302083.5
		600	148789.3	40.8	29402.6	8.1	45903.5	12.6	140776.3	38.6	364871.7
		700	161558.9	43.5	21922.3	5.9	38535.8	10.4	149728.6	40.3	371745.6
		800	150320.3	41.8	16135.2	4.5	27296.3	7.6	165576.0	46.1	359327.7
		900	132265.4	36.5	19842.8	5.5	14075.2	3.9	195699.9	54.1	361883.3
		1000	98180.1	40.6	8938.4	3.7	10700.1	4.4	124297.3	51.3	242115.8
SP	I	50	7867.1	45.2	5679.1	32.7	2876.7	16.5	968.3	5.6	17391.1
		100	18184.8	55.0	1462.5	4.4	4745.4	14.3	8695.4	26.3	33088.1
		150	24605.5	50.4	2094.8	4.3	2492.2	5.1	19592.6	40.2	48785.1
		200	33868.4	52.5	2774.9	4.3	3557.8	5.5	24281.0	37.7	64482.2
		300	100724.3	57.2	11925.0	6.8	11105.2	6.3	52300.7	29.7	176055.2
		400	127870.0	53.5	14111.3	5.9	28494.7	11.9	68367.2	28.6	238843.3
		500	144313.4	47.8	18873.3	6.3	50523.5	16.8	87921.1	29.1	301631.3
		600	126229.4	38.5	22541.4	6.9	49134.6	15.0	129546.6	39.6	327452.1
		700	118347.7	37.3	30742.1	9.7	30859.7	9.7	137449.6	43.3	317399.1
		800	119063.8	36.5	18080.2	5.5	17174.1	5.3	171840.9	52.7	326159.0
		900	119883.3	35.6	12467.9	3.7	11998.9	3.6	192027.9	57.1	336378.0
		1000	128858.6	37.0	23056.6	6.6	15716.6	4.5	180795.5	51.9	348427.2
SP	P	50	3999.5	22.5	3543.8	19.9	2195.4	12.4	8032.5	45.2	17771.3
		100	12555.7	37.5	2750.8	8.2	6494.6	19.4	11667.1	34.9	33468.3
		150	24142.8	49.1	1632.8	3.3	4971.2	10.1	18418.5	37.5	49165.3
		200	32146.9	49.6	2830.8	4.4	5671.2	8.7	24213.5	37.3	64862.3
		300	94318.9	53.3	14509.0	8.2	10937.6	6.2	57050.1	32.3	176815.6
		400	127010.6	53.0	16121.5	6.7	20289.4	8.5	76182.2	31.8	239603.7
		500	143132.5	47.3	22372.8	7.4	53845.7	17.8	83040.8	27.5	302391.8
		600	136852.2	38.8	31027.9	8.8	44882.1	12.7	139904.5	39.7	352666.7
		700	137240.8	40.4	21616.2	6.4	32127.4	9.5	148570.8	43.8	339555.3
		800	140390.6	41.0	16794.8	4.9	24233.4	7.1	160603.4	47.0	342022.2
		900	121511.5	34.7	15845.7	4.5	12514.0	3.6	200312.2	57.2	350183.4

1000	109797.7	37.2	16917.3	5.7	10865.1	3.7	157585.1	53.4	295165.2