# Conservation and Cattle Production:
# Improving the Matrix Through Silvopasture

by

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## Executive Summary

Conversion of Nicaragua's tropical dry forest to cattle pasture has left a highly heterogeneous landscape where pasture is maintained against forest succession. Climate change threatens to exacerbate these divisions between conservation and agriculture by drying up limited water sources for cattle and endemic species alike. Our client, Paso Pacífico, was interested in researching the potential of silvopastoral practices in the Rivas Isthmus of Nicaragua. Silvopastoralism combines the interests of cattle ranchers and conservationists by improving cattle production through multifunctional afforestation measures and alternative pasture management practices. This work builds on the previous Master's work on living fence rows (Dorgay, Muelle & Klooster 2016) in Nicaraguan cattle ranches by focusing on the impact of isolated trees in pastures on non-migratory birds, pasture and cattle health. This is the first study to combine these elements of the pastoral agroecosystem with a survey of farmer perceptions into an interdisciplinary study.

We began our study with a literature review of studies concerning isolated tree impacts and silvopastoral practices. We then visited 17 cattle ranches in order to complete observational studies of native birds, measurements of pasture quality and cattle health, and semi-structured interviews with farm managers or landowners. As a result, we found that non-migratory bird visits are positively correlated with isolated trees with wide and sparse canopies and available fruit. The isolated trees were also found to have suppressed pasture grass growth yet maintain overall nutrient content underneath their canopies. However at the farm-scale, we found no correlation between the overall tree cover on ranches and cattle health suggesting supplemental feed by the trees and farmers. Overall, farmers viewed isolated trees as beneficial to cattle production and the environment.

The culmination of our work is a set of recommendations to develop a culture of silvopastoral practices. The case for planting additional trees on private pasture land is supported by the evidence of lack of natural tree replacement and widely recognized benefits for cattle. By approaching incremental afforestation of cattle ranches at the landscape level, Paso Pacífico can maintain tree species diversity while incorporating farmer preference in tree plantings. Within any resulting afforestation program, a particular focus on preserving trees with wide canopies, fruiting trees, and dying or dead trees in place will preserve an unique set of resources for native birds. Finally, we recommend that future research and program design build on these studies of living fence rows and isolated trees to investigate the specific influence of socioeconomic factors and the conservation impacts of silvopastoral practices for a diversity of taxa.

## Acknowledgements

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# 1. Introduction

## 1.1 The Conventional Narrative of Agriculture

Agriculture and conservation have long been at odds with one another. For roughly 12,000 years, humans have used agricultural systems to produce food for our planet's ever-growing population (National Geographic 2017). The adoption of industrialized agriculture over the past 200 years has exacerbated this issue, trading short-term crop productivity for long-term ecological health (Foley et al 2005). As of 2011, agriculture accounted for 38.4% of the world's total terrestrial area (FAO 2017). Unfortunately, this dramatic land conversion and intensification over time has also led to irreversible biodiversity loss and ecosystem degradation (Tilman et al. 2001). These inconvenient truths indicate that our current system of global food production is not sustainable.

Some have suggested that further intensification of existing agricultural land is the solution, that is, a separation of agriculture and wilderness. While such land sparing in theory prevents agricultural expansion and preserves wilderness biodiversity, evidence suggests that intensification may escalate future conservation costs (Phelps et al. 2013). Furthermore, this system does not address the rapid degradation of existing agricultural lands nor the species that live and interact within them. Meanwhile, habitat destruction and the expansion of agricultural land continues in many parts of the world despite protest by environmentalists.

Thankfully, an alternative exists which rejects this dichotomy entirely. Through a better understanding of the relationships in the natural world through science, leaders have managed to construct agricultural systems that exist in harmony with endemic plant and animal lives. As an example, shade-grown coffee has become an especially important refuge for biodiversity, especially in areas previously deforested (Perfecto et al. 1996). This land sharing ethos examines the possibilities of systems in which agricultural production and conservation can exist in harmony

## 1.2 Tropical Dry Forest: A Globally Endangered Ecosystem

Tropical rainforests have captured the imagination of the public and researchers alike; however, the tropical dry forest (TDF) is just as globally important and even more threatened (Sánchez-Azofeifa et al. 2005, González-Rivas et al. 2006). Similar to a tropical rainforest but with a more pronounced dry season, TDFs sequester carbon, provide habitat to an array of unique biodiversity, supply local communities with natural resources essential to their livelihoods, and face the ongoing threat of conversion to agriculture. Nevertheless, this unique ecosystem is woefully understudied. TDFs provide critical ecological and economic resources. Despite their conservation value, less than 2% remains intact today (Janzen 1988). These ecosystems are now globally endangered, making our study area especially salient to conservation. Due to their favorable climatic qualities, TDFs typically experience agricultural conversion, making this ecosystem especially vulnerable to degradation. High global fragmentation of TDF poses an insidious threat, as fragment size positively correlates with species richness: the smaller a patch of forest, the fewer species it supports (Portillo-Quintero and Sánchez-Azofeifa 2010, Terborgh et al. 2008). The low extent and high fragmentation of Nicaragua's TDFs place its forests in particular severely at risk (Miles et al. 2006). Ranching, a low-investment opportunity to build income, poses an important threat to Nicaragua's remaining TDF, thus identifying alternative land management options is crucial. Management strategies that maximize biodiversity conservation without compromising economic returns are particularly important in areas that could potentially connect forest fragments in these densely populated landscapes.

## 1.3 Deforestation and Agriculture in Nicaragua

Over the past half century, Nicaragua's TDFs have been heavily deforested, mostly due to agricultural conversion and timber production (Zeledon et al. 2009). In 1981, an Agrarian Reform law expropriated and redistributed abandoned, idle and under-used lands for agricultural purposes, affecting nearly 30% of Nicaragua's arable land. Over the following decade, Nicaragua experienced severe national foreign debt in the wake of dictatorial Somoza regime which had ended in 1979. Ongoing civil war between the socialist Sandinistas and right-wing Contras continued to erode the country's infrastructure and economy until exports had declined by 50 percent and GDP had fallen by two thirds (Ocampo 1991). In 1990, the new Ortega administration then supported and gave land to private companies to increase agriculture and timber production in hopes to repay the country's debt (Mowforth 2014). As a result, between 1990 and 2010, Nicaragua lost over 30 percent of its forests, roughly 1,400,000 hectares.

Today, forest covers less than 26 percent of Nicaragua's land while agriculture accounts for over 42 percent, most of which is permanent pasture, the same land use we observe in this study (CIA 2017). Agriculture--which employs 31 percent of Nicaragua's labor force and accounts for 17 percent of the country's overall GDP (CIA 2017)--makes large -scale reforestation efforts untenable . Consequently, agricultural land sharing systems such as silvopasture may play a key role in efforts to restore ecological integrity in these heavily transformed areas.

## 1.4 Silvopasture Provides Resources to Biodiversity and Protects Farmer Livelihoods

Silvopasture is an agroforestry practice that integrates livestock, forage production, and forestry. Silvopasture systems show a wide range of tree cover, from farms that possess few shade trees to those with a large percentage of highly diversified canopy; tree and shrub arrangement exist on a spectrum from opportunistic without much planning (e.g., as remnant trees in pasture), as components of broader property management (e.g., living fencerows and windbreaks), to highly managed and deliberate aspects of cattle husbandry (e.g., alley cropping systems with trees chosen for timber value). Silvopastoralism offers opportunities to diversify natural resource management while maintaining productivity and livelihoods. In doing so, it also provides more resources to biodiversity by improving resources and connectivity through the agricultural matrix. One such way it does so is through the connection of metapopulations via forest fragments, which is important because research demonstrates that increased connectivity reduces the risk of inbreeding depression, among other ecologically detrimental situations.

Although limited numbers of trees are traditional components of pasture management in Nicaragua, local producers may eschew high tree cover for fear of reduced grass productivity. Increased canopy cover, however, can provide many services that in turn increase productivity of livestock, reduce operations costs, and, in the case of production diversification, reduce risks of market price fluctuations. Silvopastoral systems have also been found to reduce the cost of weeding and risk of fire, and living fences used in silvopastoral systems can reduce the cost of fence maintenance in farms (Devendra and Ibrahim 2004). Shade provided by such systems also decreases cattle temperature, which is linked to an increase in calving rate and milk production. Thus, tree cover actually provides services to cattle and farmers, and can lead to more efficient cattle production (Esquivel-Mimenza et al. 2011, Paciullo et al. 2011).

It is often thought that agriculture is solely detrimental to biodiversity, when in reality, certain types of agricultural matrices can support high amounts of biodiversity (Goulart et al. 2011). Silvopasture improves the agricultural matrix and creates connectivity for many species. This can be accomplished in many ways, from live fences and shrubs to highly managed and deliberate increased canopy cover. Increased canopy cover often comes in the form of isolated or remnant trees, which have beneficial effects for canopy dwelling biota, and enhance structural complexity, floral biodiversity, and faunal diversity (Guevara et al. 1998, Harvey and Haber 1998). An example of this is shown in a study that collected data from 126 sites on 33 farms, which found that tree canopy decline lead to bird decline (Fischer et al. 2010). Harvey et al (2006) explored the diversity of animal taxa associated with different forms of tree cover in agricultural landscapes found significant differences in species richness and abundance among plot types, with riparian forest having the highest and pasture with low tree density having the lowest. This same study also found that pastures with high tree cover did not differ from forest in terms of species richness. This means that a high quality agricultural matrix operates as an extension of the forest on some levels, suggesting that matrix quality improvement still provides opportunities for conservation.

## 1.5 Social and Climatic threats within Nicaragua's TDFs

The promise of silvopastoral practices gains greater significance when placed in the context of the social and economic vulnerability of cattle ranchers in Nicaragua's Pacific coast region. Nicaraguans represent one of the most vulnerable populations in Latin America with a per capita Gross National Income (GNI) of $1,940 - the second lowest only to Haiti (World Bank 2015). Recent weather events, such as a drought due to the El Niño Southern Oscillation and Hurricane Otto, are part of the growing evidence that more intense droughts and storms will occur in this region in the future. In addition, the recent plans to build a transoceanic canal through the region prioritizes the development of global trade which can add further instability to the livelihoods of cattle ranchers.

In recent years, Nicaraguans have faced many hardships as a result of of extreme weather events. In July 2016, the Caribbean coast faced intense rainstorm flooding, leading to the evacuation by the Nicaraguan Government of 4,000 people from the Región Autónoma del Atlántico Norte (Davies 2016). During the following November, hurricane Otto made landfall near El Delirio on November 24th, 2016, and crossed the country to emerge as a tropical storm from the Pacific coast south of Rivas. This hurricane was the latest in the season and had the landfall furthest south of any on record (The Weather Channel 2016). For the Pacific coast of Nicaragua, this storm comes after years of drought starting in 2014 where the expected wet season precipitation began later and provided less rainfall than expected (de Castro 2016). Those on the Caribbean coast have suffered from displacement by evacuations and destruction of their homes while those on the Pacific coast have seen their livelihoods dependent on agriculture and cattle ranching threatened by drought and an unexpected hurricane (Balch 2016).

The current political and economic climate of Nicaragua undoubtedly plays a significant role in local land management decisions over both pastureland and remaining tropical dry forest fragments. One particular international development project, a Nicaraguan canal, is both emblematic of the country's increasing desire to work with emerging international donors and how that can supercede local Nicaraguans' decision making power (Figure 1).

On June 15, 2013 the President of Nicaragua, Daniel Ortega, and Nicaragua's National Assembly signed a 50-year agreement between the Country of Nicaragua and a Chinese billionaire, Wang Jing, and his development company to create a transoceanic canal through the country. The planned path of the canal traverses the lands and fishing waters of many Nicaraguans. Under current Nicaraguan law, HKND would only need to pay the lesser of the cadastral value or market value of the land. The Executive Vice President of HKND has said through an interview that the company has a commitment to pay above the legal minimum (McDonald 2016). As for resettlement and economic sustainability for these Nicaraguans, the Executive Vice President stated that HKND will follow the minimum legal standards set by the Government of Nicaragua and will offer employment on the canal to all displaced persons (El Nuevo Diario 2015).

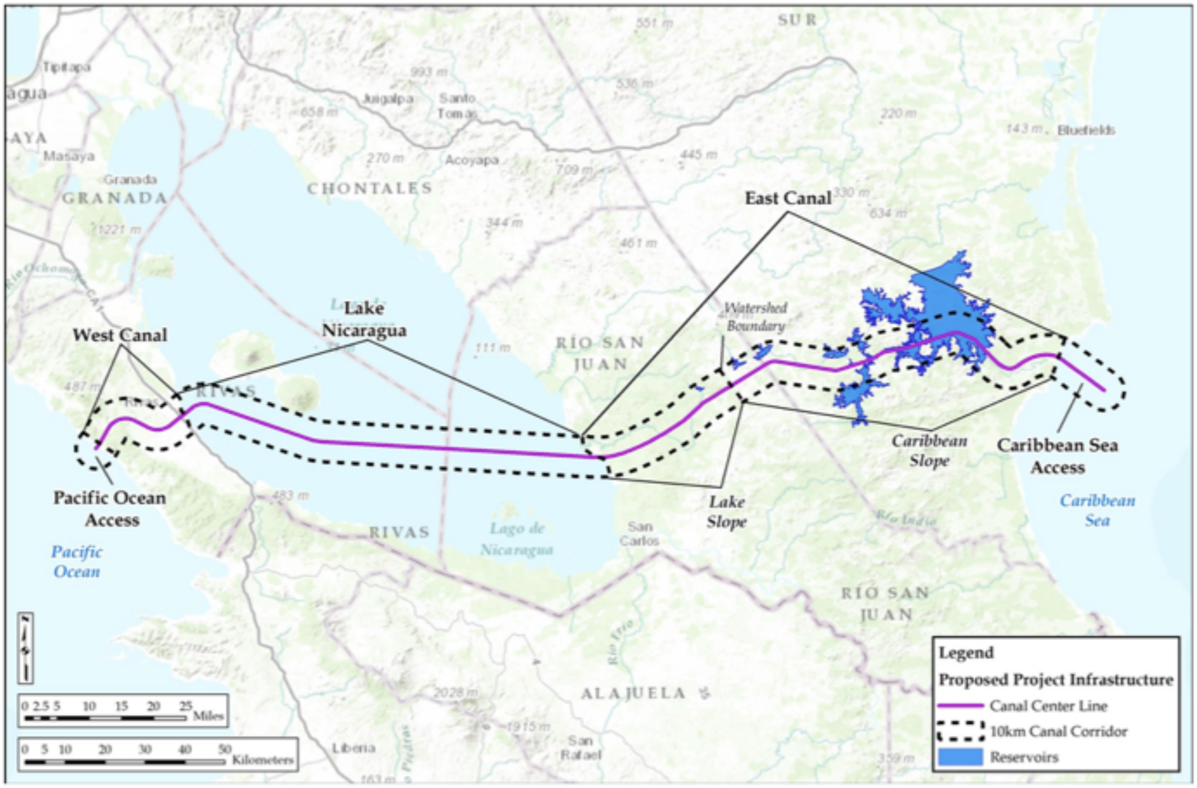



Figure 1. Official map of planned canal by Hong Kong Nicaragua Development (HKND)

On the Pacific coast side, farmers and cattle ranchers have settled land through the agrarian reform enacted soon after the Sandinista National Liberation Front overthrew the Somoza regime in 1979. As previously mentioned, the company plans to address relocations by paying fair market value for the land. Yet for those with little land or livelihoods based on agriculture and ranching, this does not mean that other options are available. One can hear this from one Pacific coast small landowner, Juan Félipe Cárdenas, “We have to leave. That’s what the Chinese say… It’s a serious problem. Where are we going to go?” (Watts 2015). The benefits of silvopastoral practices would lend stability and greater productivity, both economically and ecologically, to the Pacific coast region. If approached regionally, these practices would build a constituency of conservationists and ranchers and increase the costs of displacing this agroecosystem.

## 1.6 Research Questions

The objective of the current study is to understand the conservation value of isolated pasture trees within the cattle production matrix. The definition of isolated tree, a tree without another other overlapping canopies with a radius of 150% of its canopy width, was chosen specifically to isolate and study the impact of a tree on pasture quality and bird visitation. In cases where a tree did not meet the definition but was isolated as a clump with a number of other trees, all individual tree diameter at breast heights (DBHs) were measured and canopy width was collected using the centroid of the clump. We view isolated trees as the center of these relationships. Therefore, four overarching questions guided the current study: 1) How do isolated trees provide resources for resident birds? 2) How do isolated trees affect pasture quality? 3) How do isolated trees provide value to cattle? 4) How do ranchers use and perceive isolated trees? A conceptual model of our study can be see in Figure 2 below.

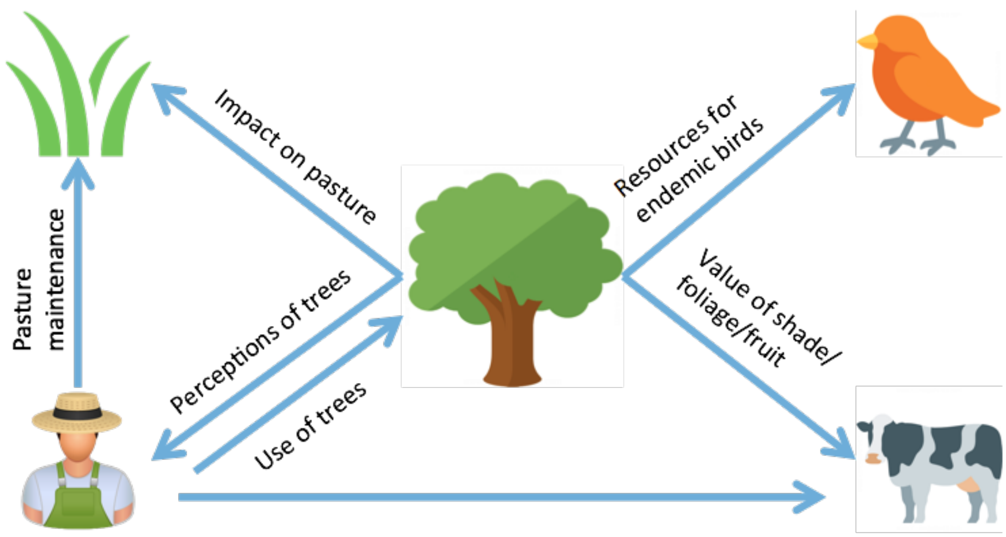


Figure 2. Conceptual model of pastoral system and the interactions of interest

## 1.7 Study Sites

We conducted fieldwork in our client, Paso Pacífico's southwestern Nicaragua's Rivas Isthmus. At just 12 miles wide, the Pacific slope of Nicaragua is a dynamic and complex landscape composed of a mosaic of cattle pasture, tropical dry forest fragments of different ages, smallholder agriculture, and teak plantations. Elevations range from sea level to 400 meters. We view this landscape as a conservation laboratory: similar agricultural landscapes now dominate the tropics, and what happens in these environments will likely predict the future of conservation. Thus, understanding and implementing alternative land management techniques is crucial to the preservation of this threatened ecosystem.

Research was conducted at 17 different sites along the Pacific coast of the isthmus during May to July 2016 (Figure 3). The ranches under study range in size from 8 to 2,800 manzanas (1 manzana = 1.74 acres) and with herds of 10 to 300 cattle. Sites were chosen to provide a variety of samples with regard to farm size, tree presence, number of cattle, and pasture quality, and the logistics of reaching the field site. The sites were primarily located in the communities of La Tortuga, Las Parcelas, Ojochal, Escameca Grande, and La Flor. A majority of farms were in production prior to the current tenure. Farms were acquired through direct purchase, abandonment, inheritance, or the agricultural reformation. Several of our farms previously belonged to now defunct cooperatives.

The forest-pasture matrix is heterogenous and fine-grained, and so most of the pastures were in relatively close proximity to a tropical dry forest fragment. However, some of the larger sites were more open and isolated from wooded patches. Additionally, most farms utilized live fences along roadsides, and in some sites, live fences were also used to separate pastures. There was substantial variation in tree density within the pasture. Some sites, such as those in La Tortuga, had high tree and shrub cover, while some of the larger scale farms, like Escamequita and Escameca Grande, were predominantly fields of grass for grazing cattle with very few trees scattered about the pastures.

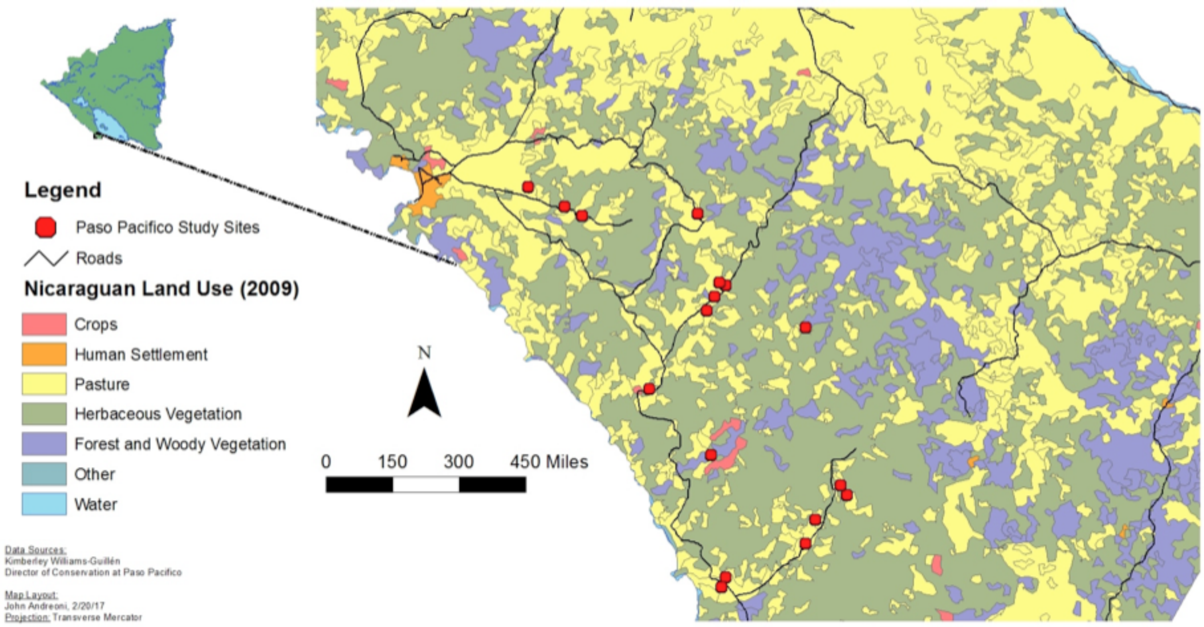



Figure 3. The Paso del Istmo study region with locations of the 17 cattle ranch study sites and land use shapefiles provided by Paso Pacífico.

## 2. Birds

### 2.1 Introduction

A long partnership exists between humans and birds, and throughout the world, birds provide essential services to human society. In China and Japan, for example, fisherman have relied on cormorants (*Phalacrocorax* spp.) to help secure a sufficient catch to sustain their livelihoods (Jackson 1997). In Africa as well, local peoples still depend on honeyguides (*Indicator indicator*) to lead them to beehives so they may harvest their honey (Isack and Reyer 1989). The Latin name of the honeyguide suggests just how deeply these peoples rely on this avian partner. In the United States, too, the field of economic ornithology thrived for nearly 50 years (Evenden 1995). Economic ornithology arose out of debates over bird preservation and persisted from 1880-1930. Highly insectivorous birds were revered as patriotic “laborers of nature” who worked alongside American farmers, fulfilling their natural duties (Evenden 1995). The post WWII explosion in pesticide use soon sealed the fate of this doomed field (Evenden 1995). Farmers forgot their avian allies and, like many agricultural producers around the world, instead turned to pesticides to defend their fields.

Nevertheless, these crucial members of the environment facilitate ecological processes and continue to provide services to both farmers and to human society as a whole. Birds provide the most diverse suite of ecosystem services of any vertebrate group (Sekercioglu 2006), so it is no surprise that these human-avian partnerships exist across the globe. Birds provide meat for food, down for garments, and guano for fertilizer; they regulate carcasses through scavenging, control insect pests, aid in soil formation and nutrient cycling, and pollinate and disperse the seeds of plants; birdwatching provides billions of dollars to economies around the world, and birds even play a prominent role in art and religion (Sekercioglu 2006). Despite the strong conservation value of birds, however, many species are in decline worldwide (Butchart et al. 2010). As a result of the alarming decline of avian biodiversity, bird-focused land management programs are urgently needed. Many of the issues that affect birds impact humans as well. A loss of birds will result in a decrease of each of the aforementioned ecosystem services that neither ecosystems nor human society can function without.

Threats to our partners include habitat fragmentation, invasive species, fisheries, window collisions, lack of resources, and climate change. Habitat loss poses a most insidious threat, however, the growing body of agroecology literature suggests that shade trees provide important resources for biodiversity in agricultural systems (Perfecto et al. 1996; Moguel and Toledo 1999; Greenberg et al. 1997; Maas et al. 2013; Sinu 2011; Williams-Guillén et al. 2006; Mendenhall et al. 2016; Luck and Daily 2003). Isolated trees act as a discontinuous, but ecologically functional canopy that can not only buffer against habitat loss, but also provide vital resources to threatened avian species like many migrants who rely on these areas as stopovers (Guevara et al. 1998). Tree cover can also provides a wide array of services to farmers (Esquivel-Mimenza et al. 2011; Harvey and Haber 1998). Aligning management practices with restoration therefore has the potential to satisfy both conservation and economic goals (Vieira et al. 2009).

The few existing studies of avian communities within cattle ranches indicate that birds prefer pasture with high tree cover over low tree cover (Mendoza 2014). Pasture trees provide important resources, and the more cover, the more benefits birds receive (Guevara et al. 1998). Common resources that these trees provide include fruit, insects, perches, and nesting sites. Pasture with high cover also provides shade and fodder to cattle, may increase cattle productivity, and provides resources to farmers such as fruit and firewood (Miles et al. 2006; Paciullo et al. 2009). As a result of the clear potential of agroforestry systems to combine the goals of habitat conservation and agricultural productivity, the current study endeavored to understand the conservation value of isolated pasture trees to resident birds. We conducted behavioral observations of birds within cattle ranches in order to answer the following questions: 1) which species use isolated trees and how frequently? 2) how do birds use isolated trees? and 3) what landscape factors and tree characteristics influence bird visitation? Ours is the first study focusing on avian behavior in isolated TDF pasture trees, and our work will elucidate how these trees can provide unique resources to bird communities.

## 2.2 Methods

We collected data on the use of scattered remnant trees within cattle pastures through behavioral observations of birds. We sampled 5-7 trees in each of 17 farms on three separate occasions from mid May to the end of June, a time period ranging from the end of the dry season through the start of the rainy season in southwestern Nicaragua. This time period occurred after migration and coincided with the end of the breeding season for many resident birds.

Sampling took place at the sites from just after sunrise, at 05:30, until 10:00, to coincide with peak bird activity. Each selected tree was observed for a period of 30 minutes during this time frame, and up to seven trees per farm were haphazardly selected for observation. Observers positioned themselves approximately 20 meters from the tree taking care not to disturb the site before or during the observation. Behavioral observations only occurred in fine weather. We also observed small clumps, defined as two to five individual trees with crowns touching or nearly touching (Fischer and Lindenmayer 2002). Trees that were parts of live fences along the border between the pasture and a road, property boundary, or interior pathways were excluded to remove confounding edge effects from the study. However, trees that were part of a live fence between two pastures were acceptable, assuming they were sufficiently isolated.

Before each observation period, the species of tree and phenological data were recorded. In order to represent the proportional presence of leaves and reproductive bodies, we used a five-point scale (Fournier, 1974). To record data on leaves, observers rated young leaves and old leaves on a scale from 0 to 4 representing 0%, 25%, 50%, 75%, and 100% density, respectively, with regard to the proportion of leaves present on the tree as compared to its potential capacity. At least one bare tree (phenological leaf rating of 0) was observed per site if possible.

The same scale was used for reproductive bodies but numerical rankings were assigned to immature fruits, mature fruits, and flowers. Observers also rated the live fence density of the pasture within which the tree was located. Again, on the same scale from 0 to 4, a number was assigned to denote what proportion of the perimeter of the pasture was a live fence. Finally, the observer recorded the start time of the observation period, the date, the name of the farm, and the farm's ID number – as assigned by the observers.

During observations, researchers recorded the species of each individual bird that made a visit to the tree, the time of the visit, any observed behaviors, and the time at which those behaviors occurred. A visit was defined as a bird landing in a tree. If the same individual left the tree and then returned during the observation period, an additional visit was recorded. Possible behaviors included perching, feeding, nesting, mating, preening, and vocalizing. We defined feeding behavior as both consuming tree products like fruit, as well as nearby prey such as insects. These behaviors were scored so that a bird could only complete each behavior once during a given visit. If no birds were observed during the 30-minute period, the data were recorded as such. In addition, all species observed using study farms outside of behavioral observations were noted and used to create a species list for each farm. These extra-study observations were collected on an ad hoc basis with similar sampling effort across farms.

After the observation period concluded, the observed tree was tagged for reference and later observation, and the observer moved on to the next haphazardly selected tree at the site, repeating each of the observation protocols. Researchers attempted to include a range of tree species and sizes in data collection. During resampling events, the trees were re-surveyed for bird visits, phenological data, and live fence ratings at each of the three visits. The order in which the trees were observed was maintained during each resurvey for logistical purposes.

We analyzed the predictors of bird visitation for statistical significance using a generalized linear mixed model modeled on a negative binomial distribution with random effects in R using the lme4 package. We investigated a variety of predictor variables including distance to wooded areas, percent tree cover, time of visit, fruit presence, flower presence, canopy width, leaf density, and live fence density one-by-one, and then used a forward model selection procedure in which we added predictors based on their individual explanatory strength until model AIC values began to increase. Exploratory analysis with Moran's I indicated spatial autocorrelation between farms and between trees, so we included tree, farm, and farm region as random effects within the model.

## 2.3 Results

We observed 61 bird species in total across our 17 study farms (Appendix 1). Of these 61 species, we recorded 29 using study trees during observation periods. The remaining species were observed anecdotally during data collection and in preliminary study site visits. We observed slightly more species at farms with relatively higher tree cover than relatively low tree cover (Figure 4), although this difference was not significant. Species richness estimates based on data collected during observation period indicate that total species richness of birds found in isolated trees is between 32 and 40, with a Shannon Diversity Index of 2.46. This estimate of species richness is in line with what we observed: we witnessed Cattle Egret (*Bubulcus ibis*) and Red-billed Pigeon (*Patagioenas flavirostris*) using our study trees outside of observation periods, but were never able to collect data regarding their use. In addition, we observed a number of species utilizing other isolated trees in our study farms including White Ibis (*Eudocimus albus*), Black-headed Trogon (*Trogon melanocephalus*), White-lored Gnatcatcher (*Polioptila albiloris*), Canivet's Emerald

(*Chlorostilbon canivetii*), Sulphur-bellied Flycatcher (*Myiodynastes luteiventris*), and Lesser Ground-cuckoo (*Morococcyx erythropygus*) that we did not observe during sampling periods.

The most abundant species recorded in observed trees were White-throated Magpie-jay (*Calocitta formosa*), Great-tailed Grackle (*Quiscalus mexicanus*), Great Kiskadee (*Pitangus sulphuratus*), Hoffman's Woodpecker (*Melanerpes hoffmanii*), and Montezuma Oropendola (*Psarocolius montezuma*), respectively. White-throated Magpie-jay (WTMJ) and Great-tailed Grackle each accounted for nearly a quarter of recorded visits. The frequencies of the three next most abundant bird species, Great Kiskadee, Hoffman's Woodpecker, and Montezuma Oropendola, were precipitously less. It is important to note that all recorded Montezuma Oropendola visits were observed in a single tree, though we observed many individuals using other isolated trees anecdotally. These birds are colonial nesters that favor isolated trees for the protection they provide from predation, and we were lucky to encounter one such tree at one of our study farms. The least common birds we observed were Altamira Oriole (*Icterus gularis*), Black Vulture (*Coragyps atratus*), Keel-billed Toucan (*Ramphastos sulfuratus*), and Roadside Hawk (*Buteo magnirostris*). For each of these species, we recorded a single visit across farms throughout the study period.

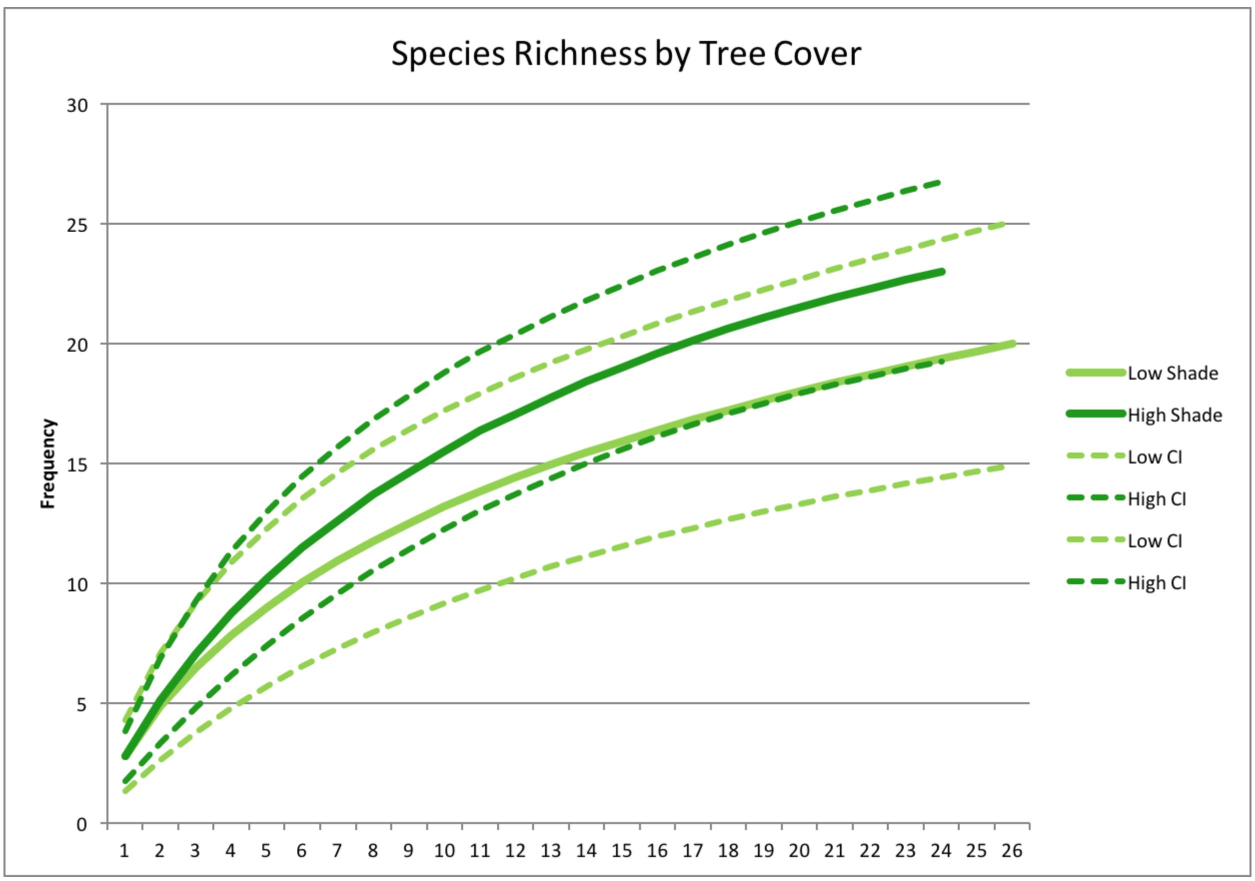



Figure 4. Bird species accumulation curve for relative high tree cover versus relative low tree cover with 95% confidence interval (CI).

We recorded six different types of behavior in observation trees (n=527). The behaviors we noted included feeding (n=45), nesting (n=30), perching (n=432), preening (n=66), and vocalizing (n=140). We also recorded a single instance of mating between a pair of Groove-billed Anis (*Crotophaga sulcirostris*). Overwhelmingly, birds used isolated trees as perches. Perching behaviors accounted for an impressive 82% of individual recorded behaviors (Figure 5). The second most common behavior we observed was vocalizing (27%), followed by preening (13%), feeding (9%), and nesting (6%). Behaviors of interest that researchers observed but did not record included defecating, tool use, and social behaviors. The behaviors we observed speak to the many resources that these trees provide to birds.

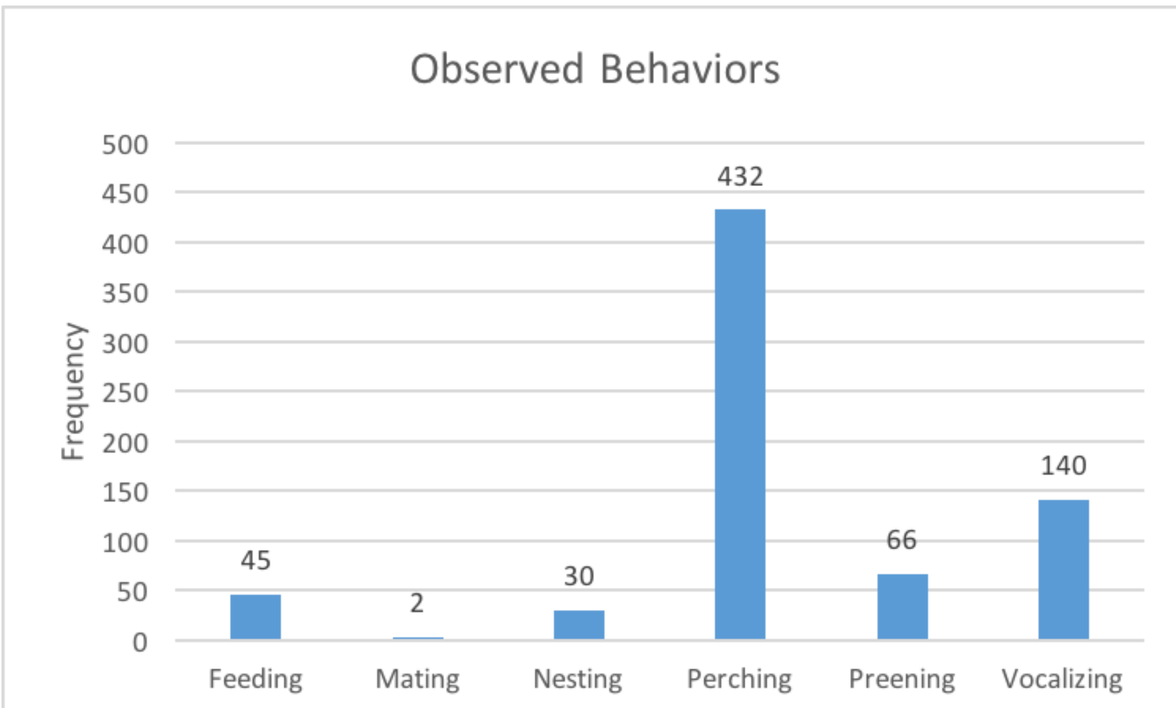


Figure 5. Frequency of observed bird behaviors in isolated trees across farms.

According to our mixed model, we found that time of day, presence of fruit, canopy width, and leaf density were the best predictors of bird visitation. We noticed a period of peak activity around 07:00, and bird visits increased significantly as minutes after midnight decreased (p=0.008). Visitation increased significantly with both canopy width and presence of fruit (p=0.002, p=0.022, respectively) and decreased significantly with leaf density (p=0.008). See Table 1 below. Percent tree cover, distance to wooded patch, presence of flowers, and live fence density had no significant effect on bird visitation. Overall, birds were more likely to visit large trees with wide canopies. The birds in our study system also visited fruiting trees more often than trees without fruit, and were more likely to visit a snag then a fully leafed out tree. These preferences suggest that isolated trees provide birds with vantage points for foraging and communication, perches for grooming and drying out wet feathers after a morning rainstorm, and nesting sites that may lower predation risk.

Table 1. Significant predictors of bird visitation.

| Fixed Effect | Estimate | Standard Error | Z value | P value |
|---|---|---|---|---|
| Canopy width | 0.19554 | 0.06222 | 3.142 | 0.00168 |
| Hours after midnight | -0.30723 | 0.11524 | -2.666 | 0.00768 |
| Leaf density | -0.29372 | 0.11139 | -2.637 | 0.00837 |
| Fruit presence | 0.62763 | 0.27554 | 2.278 | 0.02274 |

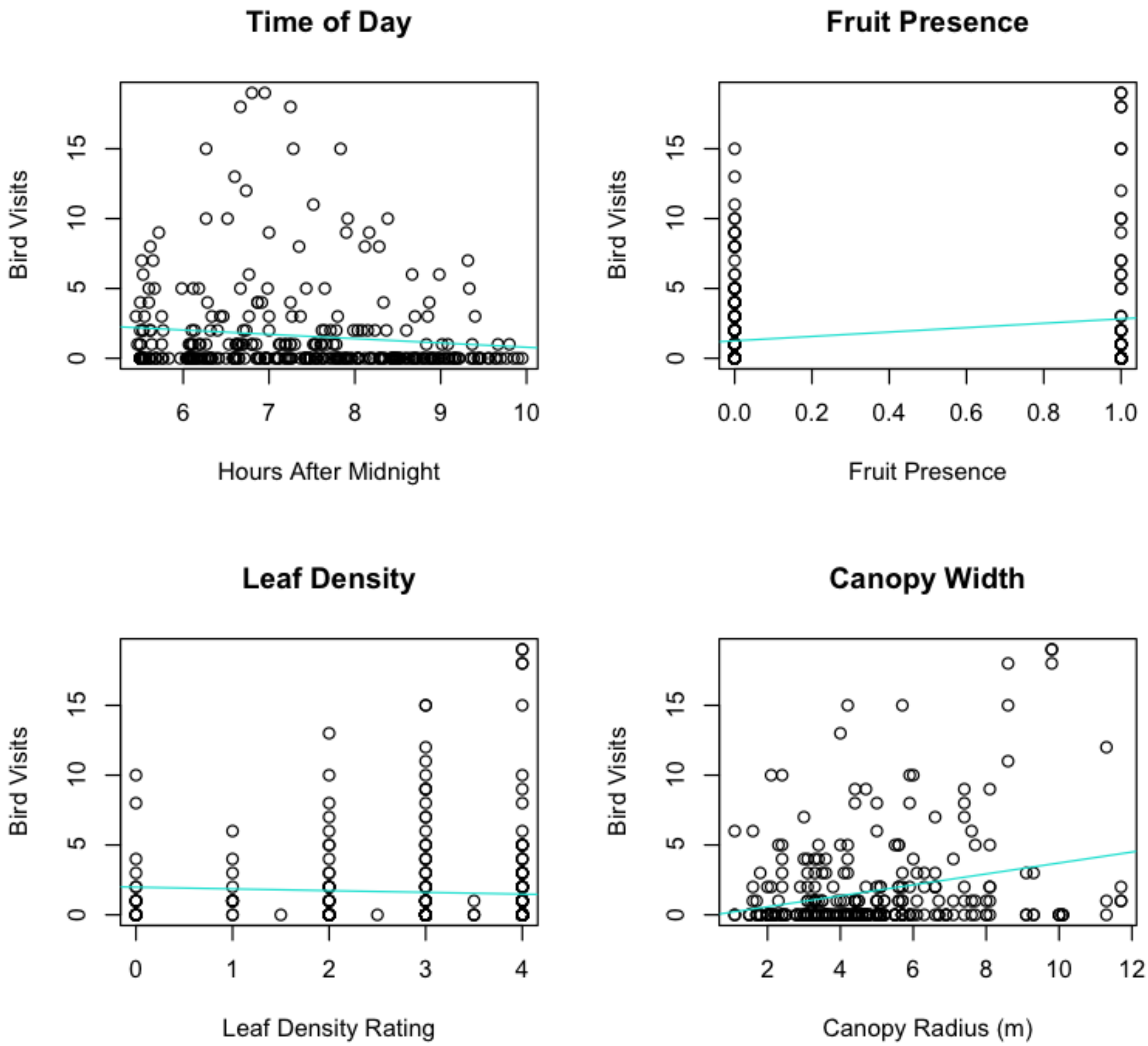



Figure 6. Total bird visits in response to tree characteristics and sampling time.

## 2.4 Discussion

Our results show that isolated trees in cattle production systems provide valuable resources for a sizeable and diverse community of birds. The community we observed includes frugivores, insectivores, omnivores, scavengers, and raptors, along with generalists and specialists. The absence of migrants from our study and initial severe drought conditions (which were associated with a die off of multiple wildlife species; Williams-Guillén, pers. comm.) suggest that we likely underestimated species richness. Additionally, we conducted behavioral observations close to the end of the breeding season for many resident birds. During this time, birds characteristically move less frequently throughout their home range as they tend to nests, so are often more difficult to spot. Birdwatchers know late summer as the "doldrums."

In addition to the 29 species we recorded, we observed roughly ten additional species using isolated pasture trees anecdotally. These trees likely hold different relative value between species, however. Two species made up almost half of all recorded observations: WTMJ and Great-tailed Grackle each accounted for roughly a quarter of all visits, with WTMJ visitation occurring most frequently (26%). Great Kiskadee and Hoffman's Woodpecker visits accounted for 7% and Montezuma Oropendola 6%. The least frequent species, Altamira Oriole, Black Vulture, Keel-billed Toucan, and Roadside Hawk each visited study trees a single time.

The two most common species, WTMJ and Great-tailed Grackle are social, noisy birds that often travel in groups, which may help explain their disproportionate representation within our observations. WTMJ have an atypical social system in which territorial groups consist primarily of related females, and males disperse at two years of age to join another territorial group (Langen 1996). These birds, however, rely heavily on pasture for resources. Common pasture trees in our study sites such as *Spondias mombin*, *Byrsonima crassifolia*, *Acromonia sp.* and *Cresecentia alata* are known to provide fruit and nesting sites to WTMJ, especially during the dry season when forest resources are scarce. Furthermore, WTMJ require heterogeneous habitat consisting of both pasture and woodland (Langen and Vehrencamp 1998). The fragmented mosaic of land use in our study sites therefore likely provides ideal habitat for our most frequent visitor.

We found that birds use isolated pasture trees for perching, feeding, nesting, preening, and mating. Each of these behaviors plays a crucial role in the survival of these birds. Trees provide fruit and attract insects that comprise an important part of many avian diets, and birds in the current study preferred fruiting trees significantly more than non-fruiting trees. Surprisingly, feeding occurred very little in study trees relative to other behaviors. This may be a result of the overall lack of fleshy fruits we encountered in pastures, and it is likely that higher feeding rates would be observed during mass-fruiting events.

Isolated trees also provide preening sites to resident birds. Maintenance behavior such as preening comprises an average of 10% of a bird's daily time budget (Cotgreave and Clayton 1994). Birds use their feathers for temperature regulation as well as mating and defensive displays, in addition to flight, so a bird must have well-groomed plumage at all times. Furthermore, preening helps to reduce parasite loads that may harm the health of birds and affect their ability to reproduce (Clayton 1991). These trees also provide important nesting sites. Building nests in isolated trees lowers the predation risk of predators such as monkeys who are loath to cross open ground, and species such as Montezuma Oropendola and WTMJ prefer the safety that these trees afford (Langen and Vehrencamp 1998). Lower predation risk can mean higher nest success and overall fitness.

During the current study, the most important resource that isolated trees provided to birds was perching sites. These perches offer locales for vocalizing, the second most common behavior we observed. Vocalizing allows birds to communicate with conspecifics and ward off invaders. Species such as Blue Grosbeak (*Passerina caerulea*) and Gray-crowned Yellowthroat (*Geothlypis poliocephala*), however, have long and complicated calls. Tropical forest trees often have characteristic waxy leaves that may prevent excessive water absorption during the rainy season. If a Blue Grosbeak were to sing in the forest, the notes would likely bounce off of these waxy leaves, rendering the call garbled and incomprehensible (Wiley and Richards 1978). Perches also provide important vantage points for hunting. Scavengers such as Crested Caracara (*Caracara cheriway*) can use these trees to scan the landscape for carrion. Isolated trees may be even more important for the Olive-sided Flycatcher (*Contopus cooperi*), one of 19 avian species of conservation concern found within our study area. Flycatchers perform a characteristic sally and return behavior when foraging: these birds sit in open areas waiting patiently for an insect to pass by. Upon identifying a prey item, the bird flies out to catch it, and returns to its original perch to consume the insect. It is no surprise then that the birds who frequent these pastures preferred snags and bare trees; trees with dense canopies would obscure their view. This finding suggests that not all trees are created equal; isolated pasture trees seem to provide different resources than forest trees. Interestingly, this finding conflicts with that of Guevara et al. (1998) that benefits to biodiversity from pastures increases with tree cover. Remnant trees that provide perches may also facilitate restoration by acting as dispersal foci (Herrera and García 2009). We noticed a number of perching birds defecating from trees, and this type of seed dispersal may lead to a positive feedback loop of reforestation within pastures. While detection issues in large, dense canopies could lead to an underestimation in species that prefer high leaf density, researchers typically observed trees in pairs and watched for birds entering trees to minimize this.

Notably, farmers see value in the birds that rely on these ranches. Though the ranchers whose farms we studied did not see any ecological benefit to a robust avian community within their ranches when asked, each was quick to offer that he does not see as many birds now as he previously has. This suggests that while ranchers perceive no ecosystem services from birds, they nevertheless see their aesthetic value, and seem to understand their absence as an environmental indicator.

Birds clearly use agroecosystems such as those of the current study, though the level of reliance likely depends on the species. In line with the large body of agroecology literature in support of land-sharing, isolated shade trees in silvopastoral systems provide resources to birds, may facilitate their movement through otherwise deforested and transformed landscape, and may provide unique resources not available in forests. The isolated trees in our system play a unique role in resource provision, and these trees occupy a niche that trees in the surrounding forest fragments cannot. Though agroforestry systems provide food, habitat, and connectivity, birds rely on surrounding forest fragments as well. Conservation planning in the tropical dry forest should combine in-farm restoration efforts with protection of nearby wooded areas to maintain a heterogeneous landscape where biodiversity can thrive.

## 3. Pasture Quality

### 3.1 Introduction

The introduction of cattle to Central America also brought with it land management techniques for arresting secondary succession with machetes and fire and the seeding of aggressive African grass species (Murgueitio 2004). These long-standing practices are sustained by the assumption that consistent management of pasturelands as separate from forested areas will maximize cattle production. However Murgueitio et al. (2004 & 2011) demonstrated that this is not necessarily the case. In their work in El Hatico, Colombia, they found increases in milk and stocking rates when rotational grazing and intensive silvopastoral systems were employed. In this case, the definition of an intensive silvopastoral system is defined by a high density of shrubs (5,000 - 30,000/ha) and trees (50 to 500/ha) within a land designated for cattle ranching (Morales 2013). Moreover, the researcher found that during 2009, the driest year in El Hatico's 40-year record, the trees and shrubs produced fodder at a constant rate and that milk production *increased* by 10% compared with the last four years (Murgueitio 2004), highlighting the essential role that silvopastoral systems can play in climate change adaptation. Other studies have found higher soil carbon, nitrogen, and phosphorus due to jícaro (*Crescentia alata*) and guácimo (*Guazuma ulmifolia*) leaf litter compared to other pastures in the Rivas area (Hoosbeek 2016) and a combination of higher organic matter, less compaction, and a more neutral pH in soils up to six feet away from live fences with Madero Negro (*Gliricidia sepium)* versus grass monoculture in Tabasco, Mexico (Villanueva-López 2014). The benefits of tree cover also extend to improved milk production in a comparison between <10% tree cover and approximately 20% tree cover especially in smaller ranches (Yamamoto 2007). Ecologically, these isolated trees represent a genetic legacy of the previous tropical dry forest yet their recruitment is threatened by the continuing use of established pasture management techniques (Herrera and Garcia 2009, Harvey et al. 2011).

In our 17 study sites in the Rivas Isthmus of Nicaragua, we focused on the following research question to investigate the interactions between isolated trees and pasture: What impact, if any, do isolated trees have on quantity, composition, and nutrient quality of pasture?

### 3.2 Methods

On each of the 17 farms visited, we completed the following field collection methods for each isolated tree or clump observed for bird behavior and additional isolated trees or clumps not observed for bird behavior when time allowed. Isolated trees were selected haphazardly by researchers on the day of sampling and thus the collected data is not a representative sampling of the tree composition and size classes of any entire farm. Our team also collected biomass samples using a 0.5 m x 0.5 m quadrat of at least one randomly-selected tree per farm and one open field site. The selection of this site was done by randomly selecting a tree that was going to be studied and tossing the quadrat out into the pasture. In total, our team sampled 149 isolated trees or clumps of trees and collected 55 biomass samples of pasture.

The team first identified the species of tree using expertise from Paso Pacifico staff and collected a photo that captured the entire tree for post-collection verification. We then sampled the tree's circumference using a transect tape and the location using either a GPS field collection device provided by Paso Pacifico or the GPS Tracks v3.02 application on an Apple iPhone.

Researchers then employed a compass and transect tape to layout three transects at 0 degrees, 120 degrees, and 240 degrees from geomagnetic North. On each transect line, the canopy width was estimated using the transect tape suspended perpendicularly to the tree trunk at breast height. This length of each transect was measured to 1.5 times the measured canopy width on that transect rounded up to nearest meter. At each meter mark on the transect, a 0.5m by 0.5m quadrat was placed and the team determined the plant height with a measuring tape at the meter mark and a photo of the entire quadrat for post-collection coverage analysis.

Before analysis, we cropped the transect photos so that only the groundcover within the quadrat boundaries were visible. Those cropped photo files were then analyzed using software developed by Martin Krzywinski with the British Columbia Genome Sciences Center (Krywinski 2017). The "image color summarizer" separated the colors of each photo into 10 major color clusters, mostly greens and browns, by image percent. Green colors--representing live vegetation--were totaled for an overall vegetation cover. Most photos were taken by our researches at roughly waist height, so we acknowledge there is likely a slight overestimate in coverage data for quadrats with greater plant heights. An example output can be found in Appendix 2.

At least three live biomass samples were collected per farm. Prior to any bird observations, the team used a set of playing cards from Ace to 7 to randomly select which tree would be sampled and near which tree the surrounding open field would be sampled. Random number generation was used to determine which transect (i.e. 0 degrees, 120 degrees, 240 degrees) would be sampled for biomass. The team laid down a quadrat centered on the selected transect at a distance of one half of the measured canopy width and one and a half of the measured canopy (Figure 7).

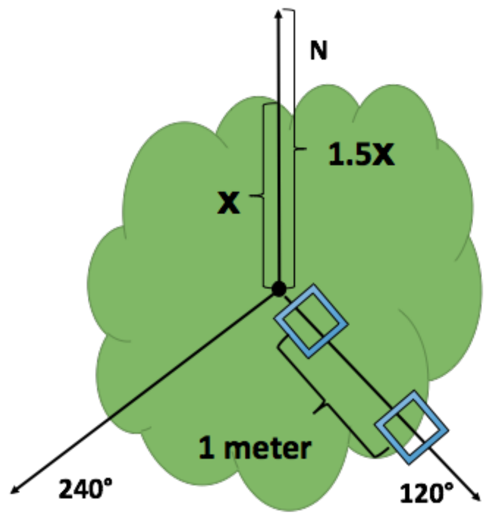



Figure 7. A diagram of the isolated tree transect sampling method.

All the living biomass within the quadrat was clipped to the soil level and collected in a sample bag. For the open field sample, a researcher flung a quadrat away from the associated tree where no other shade trees existed and biomass was clipped to soil level where it landed. Ten tree species were represented in the 18 trees randomly selected for biomass sampling. Following the collection of biomass, all woody biomass was separated, and the nonwoody biomass was dried using a dehydrator provided by Paso Pacifico. The dried biomass was further separated by grass and non-grass morphospecies when possible and then weighed separately using a scale with an uncertainty of 0.5 g. All the samples of biomass were then transported from Nicaragua to the United States for nutrient analysis using the LECO TruMac Series device. For analysis with the LECO device, a representative subsample of the dried biomass samples was ground using a coffee grinder. These ground subsamples were then run in duplicate using a mass of approximately 0.2 grams each through the device. As part of standard procedures, a blank and reference material were run alternatively as every tenth subsample.

All data analyses were completed using the open-source R software. For biomass data analysis, we controlled for date of sampling since a significant positive correlation was found between date of sampling and grass morphospecies mass (Appendix 3). When analyzing the percent nitrogen and carbon, we also controlled for species since it significantly explained variation in percent carbon of biomass samples and had a significant interaction with date sampled for percent nitrogen. A subset of the data, 48 of the 55 samples, were analyzed with separate grass and non-grass morphospecies' masses.

## 3.3 Results

### 3.3.1 Biomass Samples

The biomass response variables of total sample mass (g), percent of total sample containing nitrogen, percent of total sample containing carbon, and the composite carbon to nitrogen ratio were all found to be normally distributed (Appendix 4). The response variables were compared across sample position (i.e. inner canopy at 0.5 of canopy width, shade region at 1.5 of canopy width, and open field) using the ANCOVA function in R with sample date as the covariate. The sample total mass was found to be significantly lower underneath the canopy than either the shade influence region or open field samples ($F_{(1,21)}$= 4.56, p-value = 0.05, Figure 8). The location of the biomass samples did not have an observable effect on the carbon to nitrogen ratio, percent of nitrogen nor carbon. We also found that grouping by phenological rating did not account for variation beyond sampling date except with near significance (p = 0.07) in one case - a Tigüilote (*Cordia dentata*) flowering at 25% of its capacity (Figure 9). The presence of a nitrogen-fixing tree was not found to impact any biomass response variables.

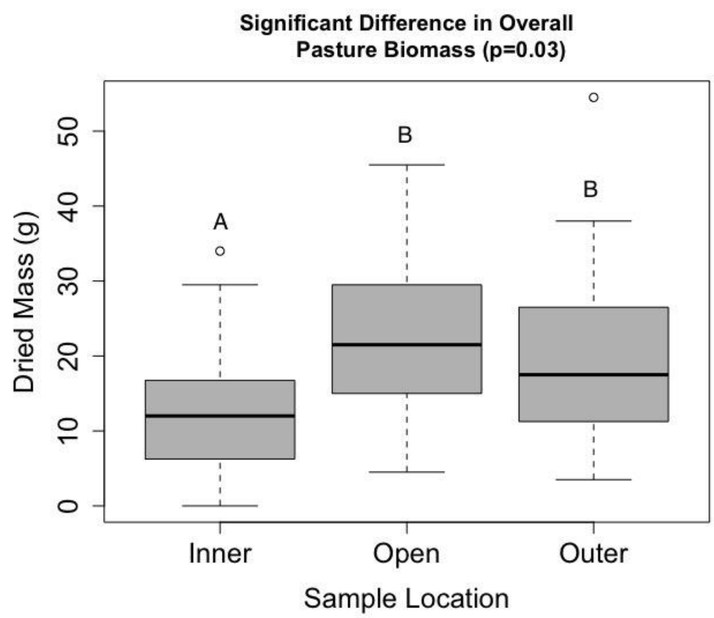



Figure 8. The inner canopy biomass samples (0.5 of the canopy width) were significantly lower than either the shade-influenced samples (1.5 of the canopy width) and open field samples.

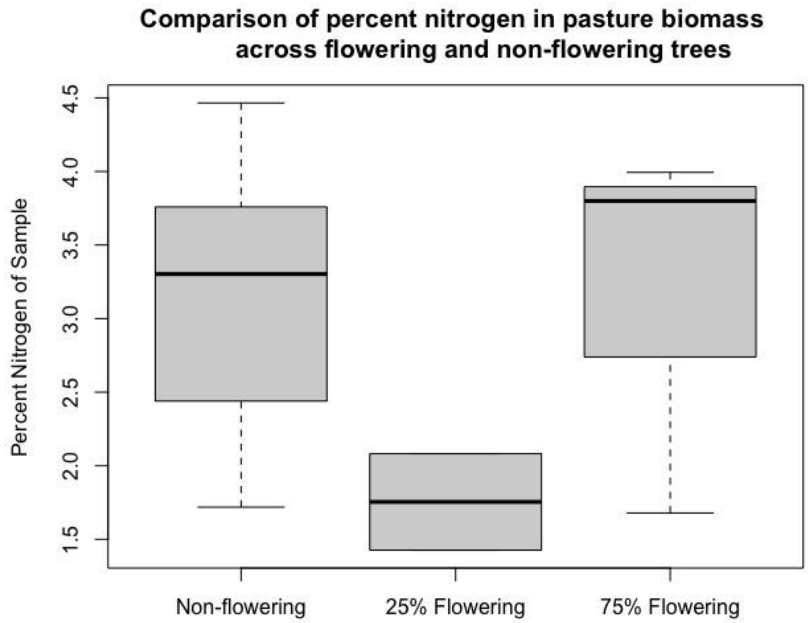



Figure 9. Boxplot of percent nitrogen found in biomass samples grouped by flowering phenological data (n = 36, p = 0.07).

We also found that the samples collected within the canopy had a significantly lower mass of grass morphospecies when compared to the grass masses of open field samples (Figure 10). Further tests also uncovered a significant negative correlation between percent of samples composed of grass morphospecies and percent nitrogen of samples ($R^2 = 0.26$; Fig. 11). No significant correlation was observed between the non-grass morphospecies mass and overall sample percent nitrogen, percent carbon, location of sampling or even date of sampling.

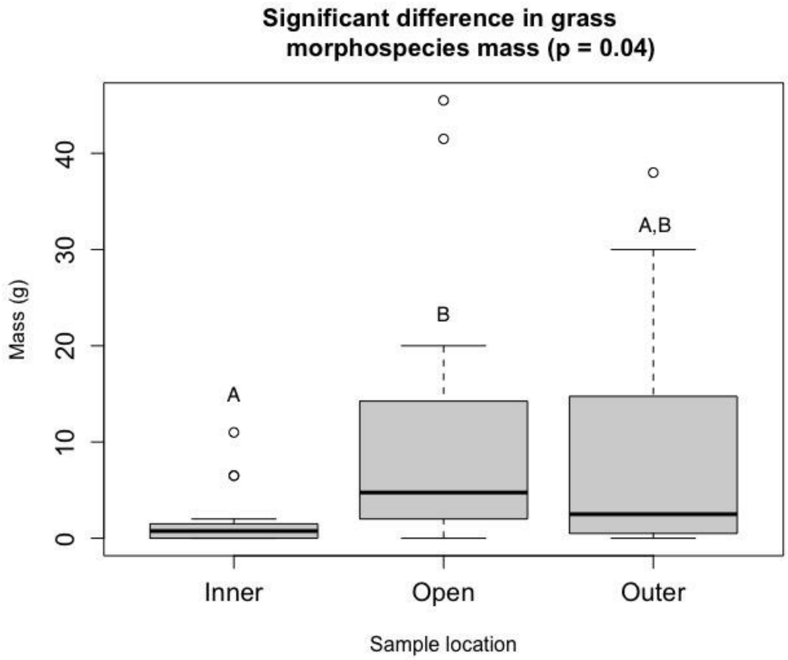



Figure 10. The inner canopy biomass samples (0.5 of the canopy width) were significantly lower than open field samples.

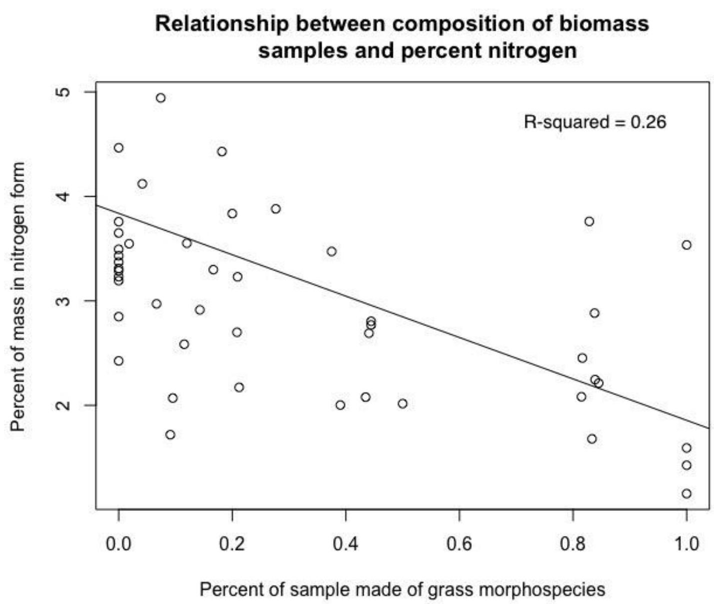



Figure 11. A subset of samples with grass morphospecies information (n = 48) demonstrated a significant negative correlation between composition of the biomass samples by morphospecies and overall percent nitrogen.

### 3.3.2 Transect Coverage

Currently, a subset of the transects have been analyzed in order to generate coverage data. From this preliminary data from 17 trees, we are able to observe a distinct directionality to both canopy width and coverage data. The canopy widths and coverage data on the north-facing transect are consistently the lowest while the values on the southeast transects (120 degrees from north) and southwest transects (240 degrees from north) are consistently higher though not significantly different from each other. The north transect was not consistently lower in isolated clumps due to varied spatial arrangement of the trees themselves.

## 3.4 Discussion

Upon initial reflection, our results do confirm farmers' observations that isolated trees suppress pasture growth and specifically the growth of desirable natural and improved grass varieties. This result is not unexpected given the expectation of light competition within the tree canopy and the ability of C3 plants to generally outcompete C4 plants in more shaded areas (Osmond 1982, Anten 2005). However, the more comprehensive transect coverage and phenology dataset does demonstrate that this impact is highly variable due to wide variability in canopy leaf density and resulting coverage data. Our findings on the correlations of later dates of sampling and lower percentage nitrogen in the samples with more grass morphospecies mass also agree with the literature on the growth habit of C4 plants (Brown 1978, Oaks 1994, Osborne 2009). We observed that grasses are able to respond more quickly in the short-term to the onset of the wet season, captured in the date of sampling, and are likely more nitrogen-efficient in that early growth.

The case of the flowering Tigüilote (*Cordia dentata*) does provide an opportunity to discuss the tree species diversity and their potential interactions with pasture. Certain species like *Cordia dentata* were only observed once during the entire sampling effort and thus comparisons using phenological, biomass, and transect data are limited. Yet this also raises a broader concern that certain genetic legacies of the previous tropical dry forest are unable to reproduce and recruit on this pastoral agroecosystem. The impacts of the loss of these tree species could affect continuous flowering and fruiting periods and nutrient flows between trees, grasses, herbaceous cover and soil microbial communities and deserve further study.

We were not able to quantitatively measure how much additional feed ranchers were providing their cattle or estimate the quantity of forage provided by the trees themselves. Of course, collection of these data would help to estimate the caloric and nutrient tradeoffs between isolated trees and the pasture loss underneath their canopies. However the correlation between sample mass and date of sampling does underline the point that pasture growth is arrested during the dry season while phenology data emphasizes that certain trees are able to maintain their canopy despite the minimal precipitation. In addition, although a significant difference between percent nitrogen was not found based on sample position, the finding that more nitrogenous herbaceous cover outcompetes grass under tree canopies does suggest more concentrated nutrient quality amongst less biomass. Disturbance by cattle and ranchers under dense trees are uncontrolled, confounding variables that could account for the lack of significant difference in percent nitrogen.

Additionally, the random selection of trees for biomass sampling did limit the number of nitrogen-fixing trees that could be compared against non nitrogen-fixing trees. As such, any conclusions that there is no correlation between nitrogen-fixing tree presence and an impact on pasture quantity, quality, or composition must be limited and likely specific to the dry season.

# 4. Cattle

## 4.1 Introduction

To assess the impacts of silvopastoral systems on the livelihoods of our dairy farmers, we looked to their primary source of income, cows. Among smallholder producers in this area of Nicaragua, most cows are considered “doble propósito” or dual purpose -- farmers use cows for dairy production and then may sell the meat when necessary. Dairy cows represent significant financial investments for farmers, who desire healthy and productive animals. In order to measure said health and productivity, we measured each animal’s weight and internal temperature. A cow’s weight is both a proxy for health (Crichton et al. 1959) and a valuation for farmers who may wish to sell their cows for meat. Meanwhile, internal temperature can indicate whether a cow is healthy or not and whether it is experiencing heat stress (Beatty 2014). The latter is important because heat stress has been shown to severely hinder milk production (West 2003).

## 4.2 Methods

At each farm, the animals were corralled into a fenced area for milking, taking place between 6am and 1pm depending on the farm. After milking, the managing farmer and workers secured each cow to a post using a lasso and additional rope around the hind legs to allow for taking measurements. During this time, one researcher transcribed the ID number on the ear tag, name (if given), breed, and qualitative observations (presence of parasites, infection, overall health). In total, we measured 154 cattle, including 121 dairy cows. At the request of farmers, we also measured and calculated the weights of bulls, castrated bulls (bueys) and non-dairy female cows. Because livestock scales are not available to farmers in the Rivas Isthmus, we approximated weight using a formula widely used by agriculture extension services which produces results within 2% of scale weight (Lush and Copeland 1930). To obtain this metric, as seen in the Figure 12 below, we measured each animal’s length from shoulder blade (A) to rear (B), and circumference (C) just behind the front leg and entered the results into the formula as follows, which we converted to kilograms: ($C^2$ x AB)/300 = weight in pounds.

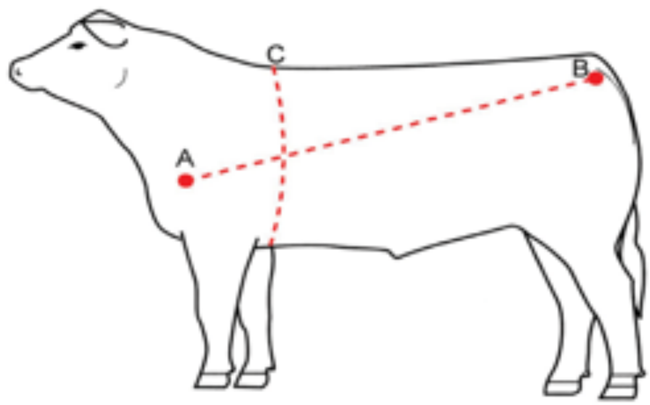



Figure 12. Measurements to be taken in order to approximate cattle weight.

The farmers we encountered were not aware of this formula and in fact had no reliable way to calculate the weight of their cows. Consequently, dairy farmers forced to sell their cows for meat found themselves at the mercy of buyers who offered prices based on sight alone. We happily shared the formula with farmers who asked, hoping to increase their bargaining power at the point of sale.

While two members of our team measured the physical dimensions of each cow, another procured the internal temperature via rectal thermometer. Rectal thermometers are considered the most accurate and reliable way to obtain a cow's internal temperature (Hicks et al. 2001). Only a few seconds were necessary to obtain an accurate reading which was indicated by an automatic alert feature on the thermometer.

## 4.3 Results

### 4.3.1 Weight

From 118 dairy cows, weights ranged from 542 pounds to 1,116 pounds with a mean weight of 817 pounds. The majority of cows were a Brahman crossbreed. The Brahman cow originated from India and has specific adaptations to heat-tolerance like less internal heat in temperatures above 24 degrees Celsius and greater capacity to perspire compared with European cattle breeds (OSU 2000). We also observed five Reina purebreds or crosses, a breed of cattle endemic to Nicaragua with a lineage that began with the Spanish introduction of cattle in the 15th century (Corrales 2011).

We regressed the measured weights of our cows against any metrics that might represent tree obfuscation of vegetation growth such as tree density and pasture land-to-cow ratio. To acquire these metrics, we analyzed satellite images of each farm, partitioning trees from pasture based on color. Figures 13 and 14 below show two of the properties we analyzed (trees are represented in black and pasture in white).

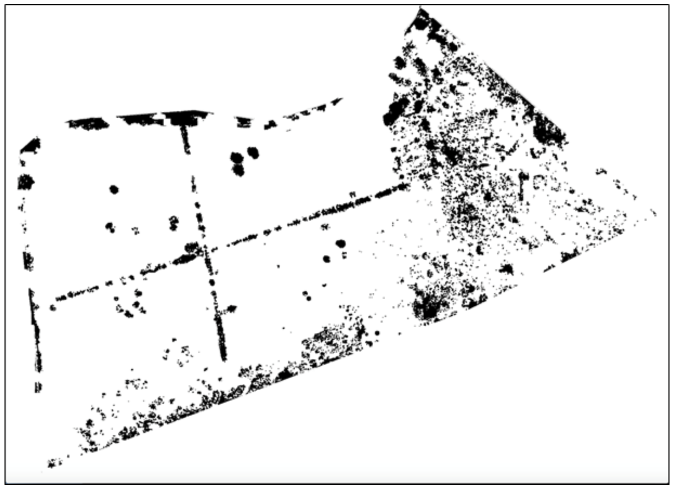


Figure 13: Escamequita orthophoto map.

Figure 14: Juan Bermudez orthophoto map.

Despite 121 cows and 17 farms ranging from 11.5% to 60% in tree cover, we found no correlation between any of of these variables. As with almost almost study, the strength of our findings would benefit from a larger sample size. Having 30 or more farms to regress would allow us to assume normality and could have provided us with more confidence in our results. Regardless, this result strongly suggests that the presence of trees are not in fact limiting cattle weight, and that these animals are limited by something else. Figure 15 below shows scatterplot of our cow weights, displayed by farm on the x-axis from the lowest tree cover (left) to the highest (right). The lack of correlation is apparent in Figure 16.

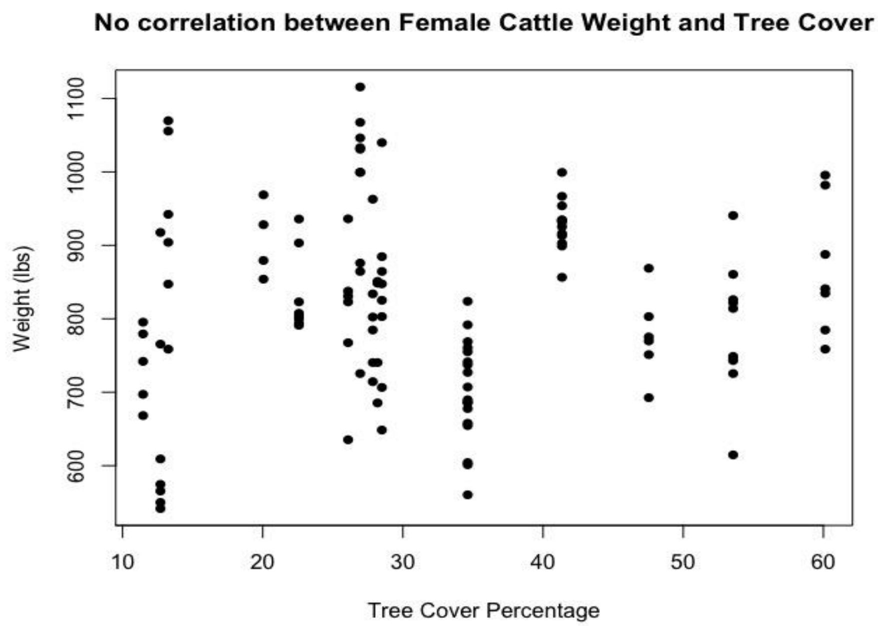



Figure 15. A scatterplot with no observed correlation between tree cover estimated using ArcGIS and satellite photos from Paso Pacífico and female cattle weight ($R^2 = 0$).

In testing, we investigated linear correlations for every predictor variable related to trees and pasture against both cattle weight and temperature, which were both normally distributed. These variables included total tree cover, feed type, sown grass variety, number of sown grass varieties. In the end, we found no significant results to explain the variation of either variable. We were particularly surprised that the use of sown grass and feed also did not correlate with cattle weight.

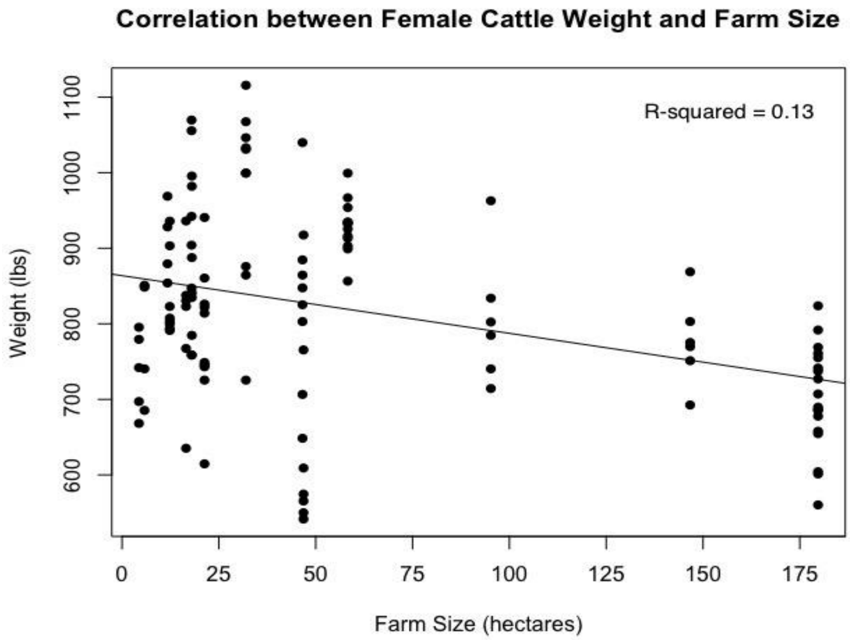



Figure 16. A scatterplot of female cattle weight with a slight negative correlation with increasing farm size.

4.3.2 Temperature

Cattle temperatures ranged from 37.2 degrees Celsius to 39.8 degrees Celsius with a mean temperature 38.4 degrees Celsius. We found a significant correlation when we regressed internal temperature against time of day and found that they were positively correlated (Figure 17). While the $R^2$ value of 0.13 suggests that the model does not have strong predictive power, the results are nonetheless significant ($p = 3.35 * 10^{-5}$)

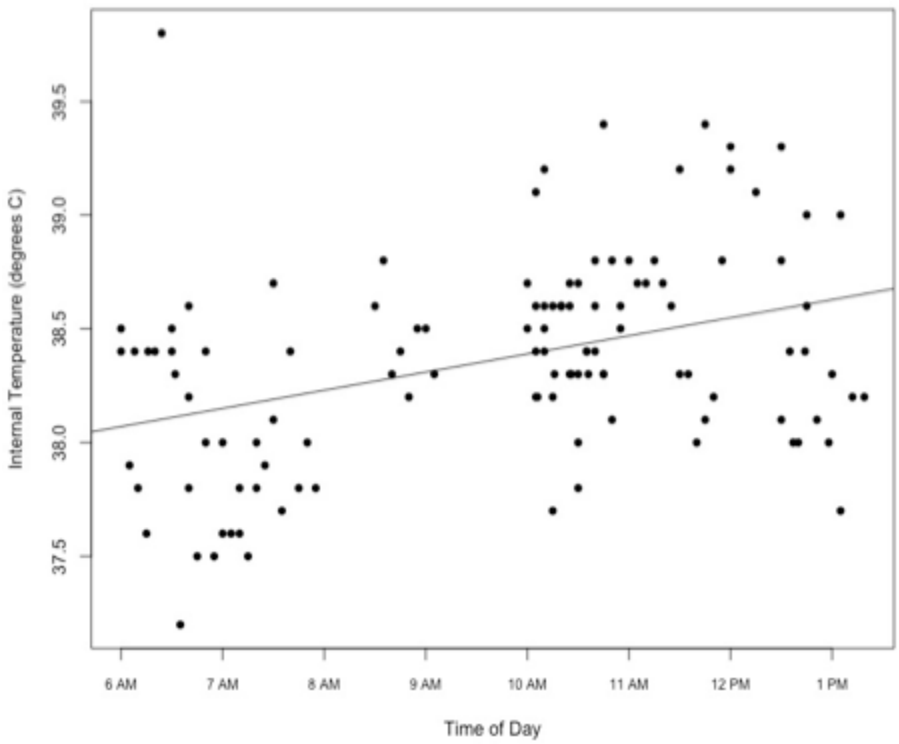



Figure 17. There exists a significant correlation between time of day and cattle internal temperature. The $R^2$ value is 0.13, but the p value is $3.35 \times 10^{-5}$.

## 4.4 Discussion

By obtaining cattle weight, we were able to examine existing assumptions regarding agricultural intensification. Nicaragua's history of clear-cutting forests for pasture land suggests that trees limit the growth of grass, a cow's primary food source, by occupying space and obstructing sunlight. Therefore, we would expect cattle weight to be negatively correlated with tree presence. However we found no such correlation, which runs opposite to the conventional narrative of pasture management. Though trees do not appear to limit the growth of the cows we measured, our tests provide no indication of what variable or variables might be limiting.

The results of our regressing internal temperature against time of day strongly support our qualitative observations of cow behavior. We routinely measured daily air temperatures exceeding 100 degrees fahrenheit. Cows like all mammals are endothermic but, as we noticed daily, appear to rely on the shade of trees to keep cool during the hot afternoons. Often, we observed large portions of a herd gathered under the large isolated trees with the dense canopies which suggests that those trees provide an important service in allowing the animals to cool, as previous studies by Harvey et al. in 2006 and 2011 have suggested. Furthermore, we believe it's possible that in pasture systems with such intense heat less than

11.5% tree cover (the lowest we measured), cows may be unable to find sufficient nearby cover and could more likely succumb to heat stress.

While the correlation between temperature and time of day is indicative of an important relationship, we were unable to measure the temperature of our cows while out in the field grazing or huddled under tree, which would have given us a more accurate representation of the temperature relationship. Unfortunately, the cows we measured were far too skittish to lasso and measure in an open field.

Although we found no significant impact of cattle breed on weight or temperature, our study was limited by the demographics of cattle breeds that commonly occur on farms. As such the endemic Reina cattle breed, which has the longest period of adapting to the Nicaraguan agroecosystem, was undersampled. Additionally the relatively recent import of Brahman breeding cattle from the United States brings up intriguing ecological questions for further study about the grazing efficiency and impact of Brahman breeds compared with Reina breeds.

In addition to providing shade, trees also can provide an important source of fodder for cattle, especially during Nicaragua's dry season (Topps 1992). Considering trees as a food source as well as a shade provider--paired with our finding that trees do not limit cattle growth--suggests that trees may in fact provide more benefits than impediments in a pasture system, at least within the systems we observed.

## 5. Farmer Perceptions

### 5.1 Introduction

Historically, the argument of conservation versus agriculture has thought to have been backed by farmers being *against* trees on their farms. However, studies show that this is in fact not the case. A survey of Costa Rican dairy farmers shows that farmers have generally positive attitudes towards trees, yet are unable to plant more because it is difficult and costly to obtain seedlings and protect them from cattle (Harvey and Haber 1998). Other studies discuss how farmers are already managing trees on their farms to fulfill a variety of farming needs that contribute to farm productivity but minimize interference with pasture productivity (Esquivel-Mimenza et al. 2011). Some reasons for having trees include risk reduction and diversification of production, as well as other benefits such as material for timber, fence posts, firewood, and shade and forage for cattle (Esquivel-Mimenza et al. 2011). Even with farmers actively using trees on their farms, the study suggests they are unaware of the potential *improvements* in cattle productivity by integrating trees and forage shrubs into their pastures. To understand the perspective of farmers on our sites, we interviewed them to gain insight on their thoughts on trees cover on their farms and to inform the cattle and pasture health analysis.

## 5.2 Methods

Our team interviewed the farmers responsible for caring for the site in order to gain insight on their livelihoods, farm care, and perceptions of trees on farms. We asked our farmers a standardized set of questions that were developed and approved by our advisors before traveling to Nicaragua. The format of the interviews were semi-structured to allow us to follow up statements to gain more detail. These questions allowed us to gain insight on the daily lives of cattle and their tree usage, how farms are operated and maintained, farmers livelihoods, farmer perceptions of and use of trees, and farmers general concerns. Most data obtained from these interviews were used to study factors potentially influencing cattle or pasture health, however this data was also used to understand the farm and farmer as a whole, which provided control data for cross-farm comparison. Our main interview questions can be found in english and spanish in Appendix 5. The questions and procedure were submitted to the University of Michigan Institutional Review Board and was considered exempt.

Interviews mainly took place with owners of the farms who also cared for the farms, but on three farms (Las Nubes, La Flor Reserva, and Escameca Grande), we interviewed the farm caretaker because the owner did not live nearby. Interviews lasted anywhere from 15 minutes to 1.5 hours. We were unable to interview the owners of one farm in the community of Las Parcelas.

## 5.3 Results

Our farmer interviews showed us that they overwhelmingly saw benefits from trees that pertained directly to their livelihoods - their cattle. Over 80% of interviewed farmers said that they notice that cattle benefit from the shade and fodder of trees. Along with this, all interviewed farmers claimed to put cattle into forested areas if they existed on their farm, particularly during the dry season, for the same reasons. Half of our interviewed farmers mentioned personal uses of trees, such as wood for building material or live fences. A quarter of our interviewed farmers also made some connection between trees and the environment; one farmer said that their watering hole will dry up if it is not surrounded by trees. When discussing the idea of having more trees on their farm, most farmers brought up the challenges associated with planting trees, such as water scarcity and the need to close off an area from cattle while trees establish, thereby reducing the pasture size. Some farmers had attempted to plant more trees on their farms either for reforestation efforts or for their own benefit, but most failed to do so for the challenges listed. Three farms have even partnered with Paso Pacifico and is actively planting trees for reforestation efforts.

Some management techniques were also similar across farms. All farmers implemented some rotation to their farms, though length of time on each paddock varied between one to fifteen days. The daily process on most farms was also similar; cattle were usually brought in to be milked in the morning and were allowed to graze throughout the day, spending the night in the paddocks. All farmers cultivated grasses, though the varieties of grasses cultivated varied widely (Figure 18). Farmers mainly cultivated one to three varieties, though some cultivated up to five varieties. One unique pasture management came from Finca Escamequita, which uses a mixture of cattle dung and water to fertilize the pasture areas. Farmers would also provide a variety of summer feeds to cattle during the dry season when pastures are not producing (Figure 19); farmers used anywhere from one to four varieties of summer feeds, though most used three. The number of annual pasture cleanings and the number of times cattle are vaccinated, given vitamins or insecticide were also similar. For these variables, most farmers claimed to perform these actions either once or twice per year. Few farmers (4) claimed to perform these actions more than twice per year, those that did performed them four times per year, two of which suggested they sometimes do administer vitamins or insecticide more than five times per year. Finally, all farmers endured some hardship from the severe drought that had plagued the region for the previous couple years. One farmer referred to the summer of 2016 as their "sixth" summer.

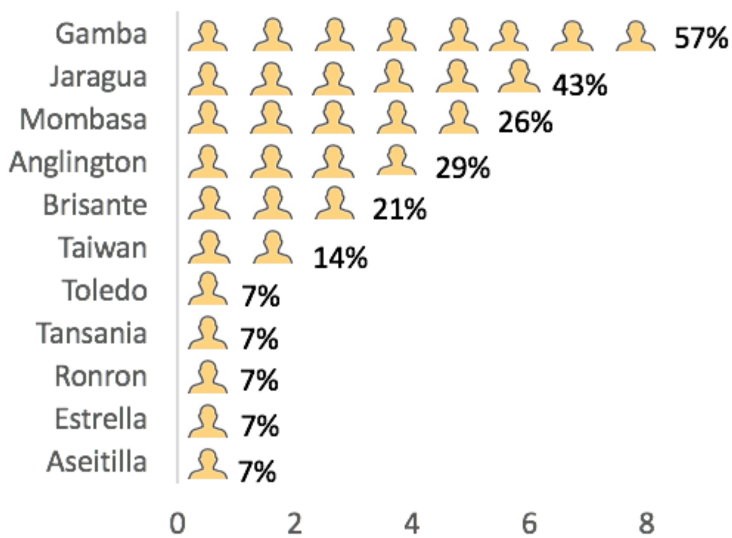



Figure 18. The variety of grasses cultivated on each farm varied widely. Most farmers cultivated one to three varieties, with some cultivating as much as five.

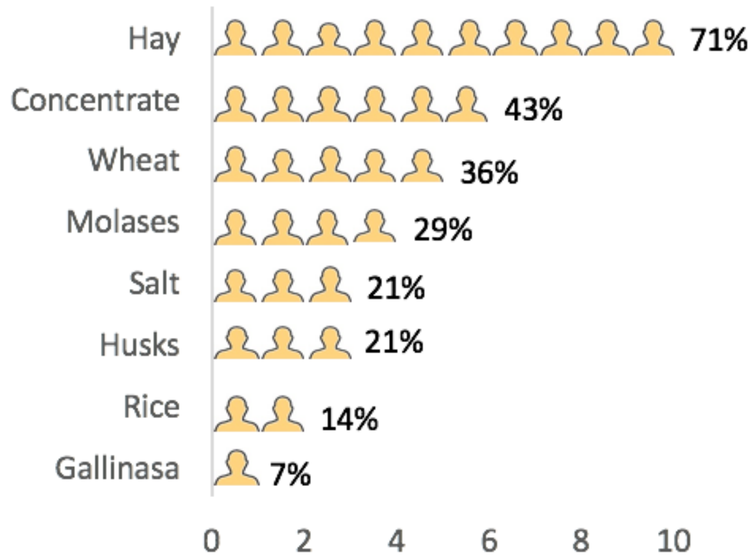


Figure 19. Farmers provide a variety of summer feeds to cattle during the dry season when pastures are not producing. Farmers used anywhere from one to four varieties of summer feeds, though most used three.

Most farmers that we explicitly asked (83%) said they would be interested in growing more trees on their farms or were already trying to grow more trees on farms, but some (33%) mentioned difficulties with keeping saplings alive whether due to cattle, soil conditions, or the drought. A quarter of farmers were particularly interested in growing more trees as live fences; this low percentage might have been essentially all farms did have live fences already.

We should also note that in some instances some questions were omitted due to circumstances outside of our control. The semi-structured format also meant that later farmers often received more specific questions and gave more detailed answers as interviewers adapted to Nicaraguan farmer terminology.

## 5.4 Discussion

Reflecting on our interviews, we see that management styles and operations have some similar qualities but contain variation from farm to farm. Overwhelmingly, we see that farmers are aware of the benefits of having trees on their farms and that they actively reap these benefits. Such perceptions are essential in order to create silvopasture systems (Harvey 2006). While these farmers did hold such perceptions, we still questioned why they weren't actively planting trees on their sites. The challenges they mentioned suggest that these farmers are interested in planting trees but need assistance in doing so. This is where conservation efforts come into play and could bridge the gap between farmers wanting more trees but and conservation needs in the region.

During our interviews we did recognize the range of wealth among our farmers, which was not officially recorded but interesting to note. It would have been difficult to ask farmers for information on income or finances, however we did see that some of the *wealthier looking* farms had better looking pastures. This could be due to an increased ability to afford seeds, which some less wealthy farmers mentioned as a challenge in pasture maintenance.

There were some limitations with gathering information from farmers. For example, we used GIS mapping to outline farms and noted that the size of farms mentioned in interviews did not entirely align with what we calculated in GIS. This suggests that in some cases, we cannot take information gathered from interviews at face value; for example farmers may report property sizes that reflect lands not used for production. This also proved to be true when discussing farm maintenance and operations; many farmers gave large ranges for the number of days they might graze a certain paddock, and listed many sown pasture varieties or summer feed varieties that they might not actually be using that year. We should also note that while farmers understand there are benefits to having trees, they may not recognize if there are improvements in yields since the timespan of tree growth is too long for individuals to notice production improvements. Another reason for impacts from trees to be misunderstood could also be because most do not physically track production, so there is no historical reference of production for them to compare.

## 6. Conclusions

Our results suggest that cattle production systems can incorporate additional trees without detriment to pasture nutrition, cattle health or farmer livelihoods, and with benefits to resident bird communities. Contrary to the widely held beliefs of some agricultural producers, we found no negative effect of tree cover on cattle health. In other production systems, shade confers a significant advantage in reducing internal body temperature (Blackshaw 1994). We also found that farmers perceive value in these isolated trees, but economic factors pose a barrier to reforestation efforts. Birds within these cattle production systems rely on isolated trees for nutrients and safe nesting sites. Overwhelmingly, these trees provide perches over open ground that facilitate hunting, maintenance, and communication. These isolated pasture trees provide very different resources to birds than do forest trees. The current study illustrates how biodiversity preservation and economic goals may converge with widespread benefits to the players in our study system, and challenges the classic notion that agriculture is the enemy of conservation (Perfecto and Vandermeer 2010).

The species diversity of isolated trees is a growing concern since recruitment is impeded by current land management practices. Consistent resource availability of nectar-producing flowers, fruits, leaves and nitrogen-fixation all depend on a diverse set of isolated tree species that vary in times of blooming, fruiting and senescence. This concern may also apply to breeds of cattle as the endemic Reina breed appears to have been displaced by the more recently imported Brahman crossbreeds. The preservation of cattle genetic diversity that developed within the Nicaraguan agroecosystem may improve the resilience of the overall system to the projected impacts of climate change.

Increased tree cover provides benefits both biodiversity and farmers in diverse agroecosystems around the world, including coffee, cacao, and tea (Perfecto et al. 1996; Rice and Greenberg 2000; Sinu 2011; Maas et al. 2013; Williams-Guillén et al. 2016). Though a high quality matrix overall supports birds, mammals, reptiles, amphibians, and arthropods, these animal groups each have unique needs and may respond differently to landscape changes (Harvey et al. 2006). In addition to benefitting biodiversity, agroforestry systems may also pave the way for ecotourism opportunities that can help the community and provide alternative income for farmers (Sekercioglu 2002).

Grazing occupies 26% of the earth's ice-free terrestrial surface, and feed crop production uses about one third of all arable land (Steinfeld et al. 2006); it is time we take a landscape-level perspective to conservation. The dynamic and fragmented landscape we see in southwestern Nicaragua is emblematic of those around the world where unsustainable agricultural conversion threatens biodiversity and local livelihoods. What happens in agricultural landscapes will therefore predict the future of biodiversity conservation and human health, for better or for worse. We have two choices: recognize the opportunities within this novel ecosystem to achieve a win-win scenario through agroforestry, or continue the unnecessary battle between conservation and agriculture.

## 7. Recommendations

Many of the farms we studied were home to isolated trees already providing important ecological benefits: snags for perching, mature trees with large canopies offering shade and protection, and fruiting trees providing food and attracting insects. We recognize the importance of keeping these trees, but also ensuring the growth of younger trees to succeed in providing these benefits in the future. Given Paso Pacifico's experience and expertise in local reforestation, we envision a partnership in which Paso Pacifico provides farmers with the direction and resources to grow these trees in pasture areas.

Our findings suggest that farmers whose pastures contain low amounts tree cover would be able to plant additional trees without sacrificing the productivity of their cows. By doing so, we expect the following benefits:

- Maintaining arboreal genetic diversity
- Perching, nesting, and fruit for local bird species
- Shade and dry season fodder for cows
- Timber for building supplies, if necessary

Balancing these priorities is important; we estimate that no single tree species can provide all four benefits at once. Additionally, our farmers already manage pastures containing trees providing some of these benefits. Therefore, we suggest that Paso Pacifico look to achieve this balance at a landscape scale, allowing some flexibility from farm to farm. While farmers may understand the immediate benefits of trees which produce good fencing such as the madero negro *(Gliciridia sepium)*, we recognize that Paso Pacifico may have to clarify the benefits less obvious to farmers.

In addition to reforestation efforts, our study found a unique value to dead or dying trees in pastures for birds. We recommend that Paso Pacifico also launch an educational campaign for ranchers to connect preserving dying trees and dead snags with significant species of concern like the Olive-sided flycatcher (*Contopus cooperi*), and to improve understanding of the many important ecosystem services that birds on farms confer. Though the ranchers with whom we spoke could not cite any ecological benefits to avian presence within their farms, most were quick to point out that they have seen a worrying decrease in bird abundance. This suggests that ranchers likely see a different value in birds, perhaps as an environmental indicator. Since the decision to leave a number of dead or dying trees involves less labor, we hope that additional knowledge of protecting native species may be enough incentive.

It is important to recognize and draw upon the wealth of experience that other organizations could bring to this endeavor. The collaboration of Colombia's Cattle Ranching Federation (FEDEGAN), Center for Research in Sustainable Systems of Agriculture (CIPAV), The Nature Conservancy, and other organizations have developed a rich set of Spanish-language instruction manuals and multi-day workshops to teach effective silvopastoral practices. We would encourage Paso Pacífico to bring experts like Enrique Murgueitio, the executive director CIPAV, or Carlos Hernando Molina, a Colombian cattle rancher with 20 years of silvopastoral experience, to run a workshop for Nicaraguan ranchers.

To address issues beyond reforestation, Paso Pacifico may want to consider partnering with government organizations. The coastal areas and the agriculture sector where Paso Pacifico works will be most vulnerable to climate change (UNDP 2010). Short term adaptation options could include programs that directly build resilience in these sectors such as workshops on seed collection and sapling care; educational programs that help ranching communities build biodigesters; provision of water catchment systems and drinking water in drought-affected areas; updating infrastructure in coastal communities threatened by sea level rise; and creating an incentive program for conservation similar to Costa Rica's Payment for Environmental Services (PSA).

Through this collaboration with the state, Paso Pacifico might also consider focusing water catchment systems in low-income rural homes, and for directly providing drinking water to low-income households in drought-affected areas. Nicaragua's National Water Authority (ANA) is charged with administering, planning, and controlling water resources and would be the appropriate agency to oversee these initiatives (Library of Congress 2016). Providing drinking water acts as a stop-gap, while installing catchment systems increases self-efficacy and resilience in the long term by increasing water security. Catchment systems also facilitate the sustainable use of a precious natural resource. Metrics for success include number of low-income households served and gallons of rainwater saved.

## 8. Appendices

Appendix 1. Complete species list for farms 1-17.

| **Species** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Altamira Oriole | X | | | X | | | X | | | | | | | | X | | |
| Banded Wren | | | | | | | | | | | | | | | | | X |
| Black Vulture | X | | X | X | X | | | X | X | X | X | X | | | X | X | X |
| Black-headed Trogon | X | X | | | | | | | | | | | X | | | | |
| Blue Grosbeak | | | | | | X | | X | | | X | | X | X | | | X |
| Blue-crowned Motmot | | | | | | | | X | | | | | X | | | | |
| Boat-billed Flycatcher | | | X | | | | X | X | X | | X | X | X | | X | X | |
| Brown-crested Flycatcher | | | | | X | X | | X | X | X | | | | X | | | X |
| Canivet's Emerald | | | | | | | | | | | | | X | | | | |
| Cattle Egret | | | X | | X | | X | | X | X | X | | | | | X | |
| Clay-colored Robin | | | | | | | | | | X | | X | X | | | | |
| Common Black-hawk | | | X | | | | | | | | | | | | | | |
| Common Ground-dove | | | X | | | | | | | | X | X | | X | | | X |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Crested Caracara | | X | X | | | X | X | | X | X | | X | X | X | | | |
| Crimson-fronted Parakeet | | | | | | | | | | | | X | | | | | |
| Double-striped Thick-knee | | | X | | X | | X | | | X | | X | | | | | |
| Dusky-capped Flycatcher | | | | | X | X | | | | | X | | | | | | |
| Elegant Trogon | | | | | | | | X | | | | | | | | | |
| Ferruginous Pygmy Owl | | | | | | | | | X | | | | | | | | |
| Gray Hawk | | | | | | | | X | | | | | X | | | | |
| Gray-crowned Yellowthroat | | | | | X | | | | | | X | | | X | | | |
| Gray-headed Kite | | | | | | | | | | | | X | | | | | |
| Great Kiskadee | X | X | | X | | | X | | X | X | X | X | X | | X | X | X |
| Great-tailed Grackle | X | X | X | X | X | | X | | X | X | X | X | X | | X | X | X |
| Groove-billed Ani | X | X | X | | X | | X | X | X | | X | X | X | X | X | X | X |
| Hoffman's Woodpecker | X | X | | X | X | X | X | X | | X | X | X | X | X | X | X | X |
| Inca Dove | | | X | | X | X | X | | X | X | X | X | X | | X | | X |
| Keel-billed Toucan | | | | | | X | | X | X | X | | | | X | | | X |
| King Vulture | | | | | | | | X | | | | | | | | | |
| Lesser Ground-cuckoo | | | | | | X | | | | | | | | | | | |
| Long-tailed Manakin | | | | | | | | | | | | | | X | | | |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Magnificent Frigatebird | | | X | | | X | | X | X | X | | | | X | X | | |
| Masked Tityra | X | X | X | X | | X | | X | X | | X | X | X | | | X | X |
| Melodious Blackbird | X | | | | | | | X | X | X | X | X | X | X | | X | X |
| Montezuma Oropendola | X | X | | | X | | X | X | | | X | X | X | X | X | X | X |
| Muscovy Duck | | | | | | | X | | | X | | | | | | | |
| Olive-sided Flycatcher | | | | | | X | | | | | | | | | | | |
| Orange-chinned Parakeet | | | | X | | | | | | | | X | | | X | X | X |
| Orange-fronted Parakeet | X | | | | X | | X | | | X | X | X | X | | | | |
| Plain-breasted Ground-dove | | | | | | X | | X | | | | | | | | | |
| Red-billed Pigeon | X | | | | X | X | | | | | X | | | X | | | |
| Red-tailed Hawk | | | | | | X | | | | | | | | | | | |
| Roadside Hawk | | X | X | | X | | X | X | | X | X | X | | | | | |
| Ruddy Woodcreeper | | | | | | | | | | | | | | | | | X |
| Rufous-naped Wren | X | X | | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Scrub Euphonia | | | | | | | | X | | | | | X | | | | X |
| Southern Lapwing | | | | | X | | X | | | | | | | | | | |
| Squirrel Cuckoo | | | | X | X | | | X | | | | X | X | | X | X | |
| Streak-backed Oriole | | | X | | | | | | X | | | X | X | | | X | X |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stripe-headed Sparrow | | X | | X | X | X | | X | X | | X | X | X | X | X | X | X |
| Sulphur-bellied Flycatcher | | | | | | | | | | | | | | X | | | |
| Turkey Vulture | X | X | X | X | X | X | X | X | X | X | X | X | | X | X | X | X |
| Turquoise-browed Motmot | X | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| White Ibis | | | X | | | X | | | | | | | | | X | | |
| White-collared Swift | X | | | | | | | | | | X | X | X | | X | X | |
| White-fronted Parrot | X | X | X | X | | X | | X | X | X | X | | X | X | X | X | X |
| White-lored Gnatcatcher | | | | | | X | | | X | | | | | | | | X |
| White-throated Magpie Jay | X | X | X | X | X | X | X | X | | X | X | X | X | X | X | X | X |
| White-tipped Dove | | | | | | | X | | | | | X | | | | | |
| White-winged Dove | | | X | | | X | | | | X | | | X | | | | |
| Yellow-naped Amazon | | | X | | | X | | | X | X | | X | | | | | |

Appendix 2. Example output from photo samples.

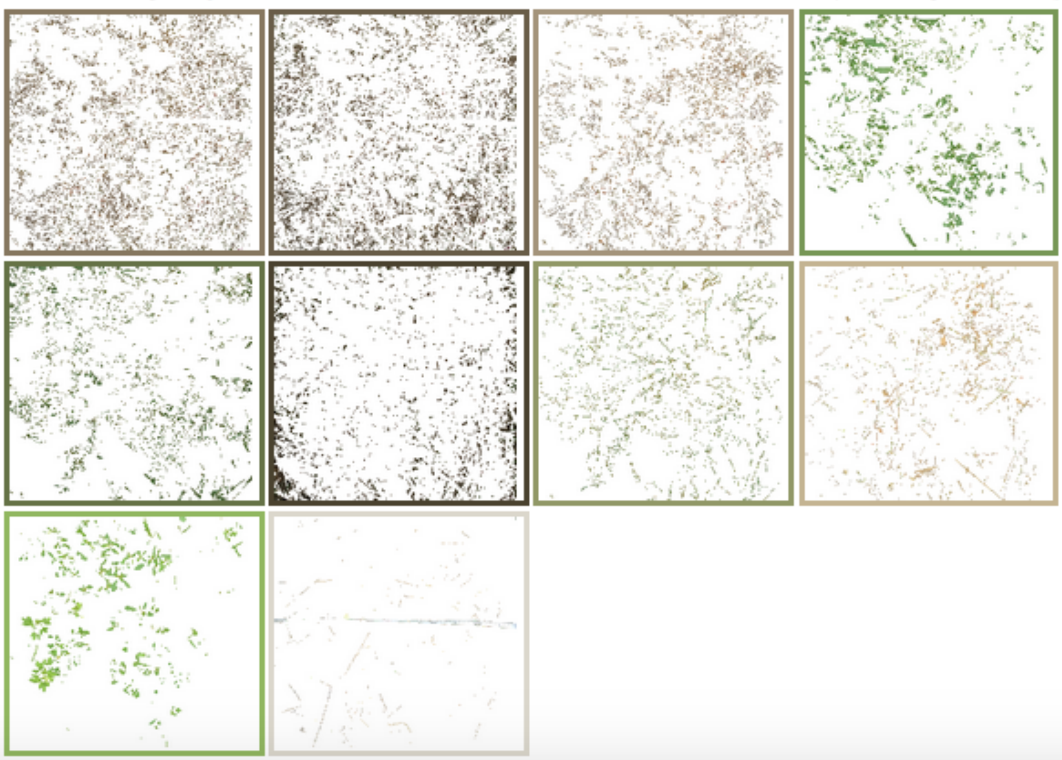
Above: an example of a cropped transect photo

Below: an image color summarizer output of the above image. In total, “greens” (vegetation) comprise of 34.34% of the ground cover.

| cluster | pixels | name | HEX | RGB | HSV | LCH | Lab | tags |
|---|---|---|---|---|---|---|---|---|
| | 17.25% | 134,119,95 brownish grey ΔE=0.4 | #86775F | 134 119 95 | 37 29 53 | 51 16 83 | 51 2 15 | aquashield brownish cement malta milky navajo nullarbor shadow stonewall triple way wheat grey white |
| | 16.71% | 111,99,75 soya bean ΔE=2.2 | #695D48 | 105 93 72 | 38 32 41 | 40 14 85 | 40 1 14 | arrowtown bandit bean coffee domino double dragon pravda soya stonewall triple wombat |
| | 13.22% | 166,146,121 donkey brown ΔE=1.3 | #A4947B | 164 148 123 | 37 25 64 | 62 15 83 | 62 2 15 | akaroa beige bronco donkey double drought gargoyle grayish half raincloud routeburn sisal triple brown |
| | 11.28% | 118,153,88 moss ΔE=1.3 | #779756 | 119 151 86 | 90 43 59 | 59 38 127 | 59 -23 31 | asparagus drab moss woodstock green |
| | 8.83% | 90,110,65 chalet green ΔE=3.7 | #657246 | 101 114 70 | 78 39 45 | 46 26 120 | 46 -13 23 | chalet green |
| | 8.68% | 72,64,44 suburban ΔE=1.7 | #4A422F | 74 66 47 | 42 36 29 | 28 12 89 | 28 0 12 | deep ash bronze double mondo onion punga suburban tumbleweed woodrush brown |
| | 7.50% | 144,155,103 westwood ΔE=2.5 | #919867 | 145 152 103 | 69 32 60 | 61 27 113 | 61 -11 25 | avocado westwood |
| | 7.32% | 190,178,145 triple fossil ΔE=2.1 | #C4B492 | 196 180 146 | 41 26 77 | 74 20 89 | 74 0 20 | beachcomber coral crusade doeskin fossil half indian khaki matchstick putty triple wheat |
| | 6.73% | 133,187,101 dollar bill ΔE=5.9 | #91B760 | 145 183 96 | 86 47 72 | 70 48 124 | 70 -27 40 | bill dollar |
| | 2.47% | 217,214,202 quarter ash ΔE=0.5 | #DBD7CC | 219 215 204 | 45 7 86 | 86 6 97 | 86 -1 6 | ash bison eighth hide linen milk pointer quarter sandspit tea timberwolf triple truffle black brown white |

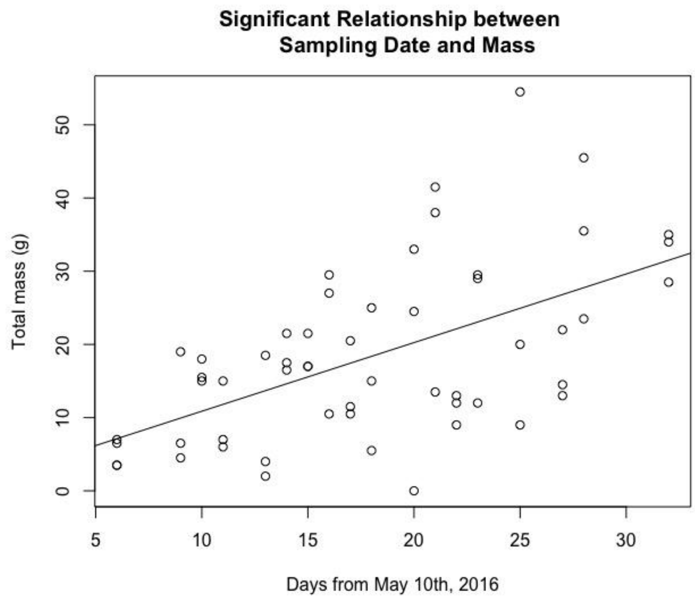
**IMAGE CLUSTER PARTITIONS**

Pixels of the image assigned to each cluster. The border is the color of the cluster as calculated by the average value of its pixels.

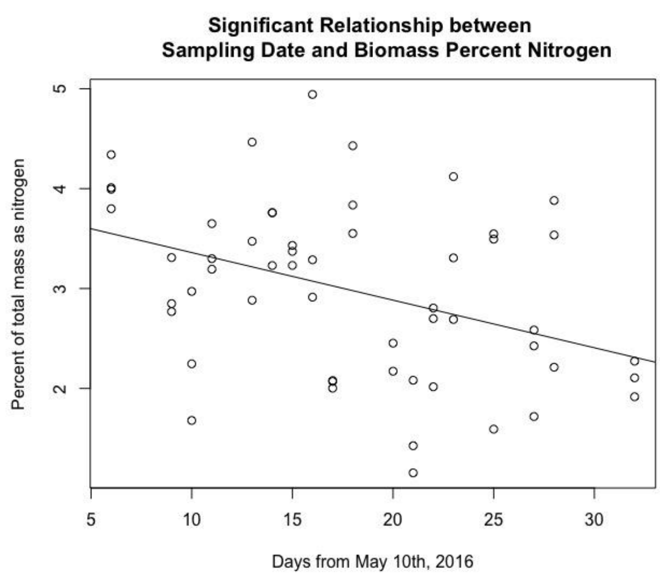


Q-Q plots of biomass data

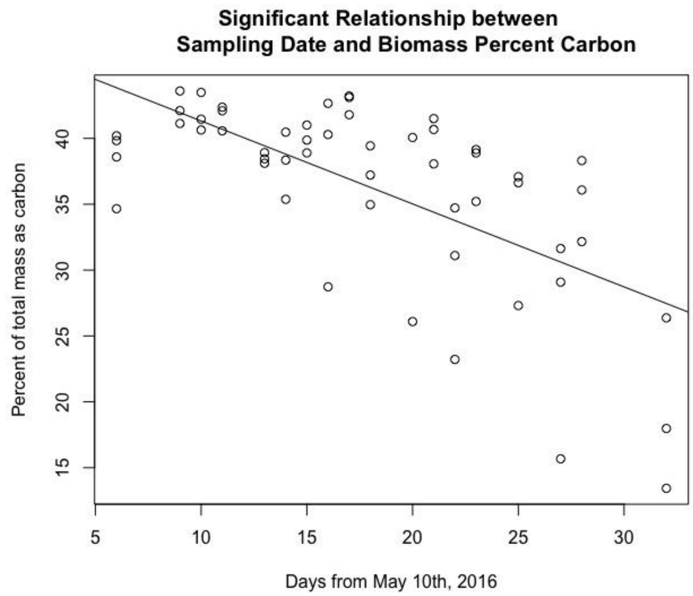
Appendix 3. Significance of sampling date on biomass.




Scatterplot of total sample mass as a function of sampling time. Adjusted r-squared value of 0.31 and p-value of 6.4*10-6

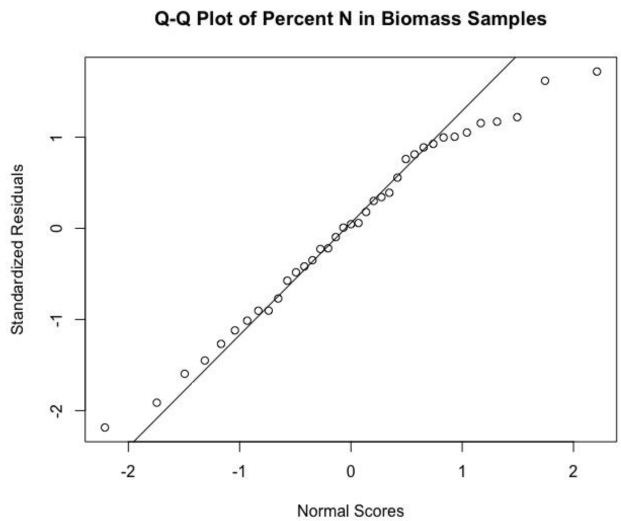


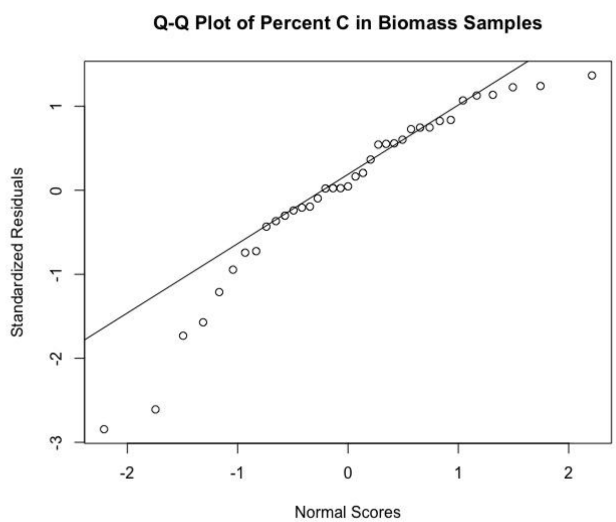

Scatterplot of percent nitrogen as a function of sampling time. Adjusted r-squared value of 0.14 and p-value of 0.003

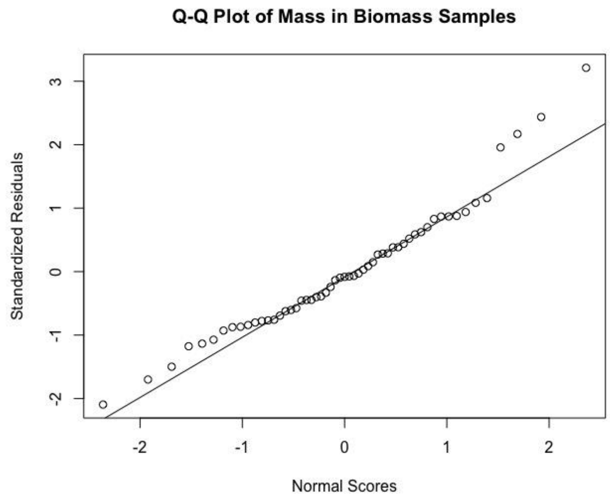



Scatterplot of percent carbon as a function of sampling time. Adjusted r-squared value of 0.41 and p-value of 1.1*10-7

Appendix 4. Normality Plots.




Q-Q Plot of Mass in Biomass Samples
Standardized Residuals
Normal Scores
-2
-1
0
1
2
3

Appendix 5. Farmer Interview Questions in English and Spanish.

**<u>In English</u>**

Observe: cow behavior and health (exoparasites - flies, ticks)
How long have you owned this ranch?
Do you own it or rent it?
How large is the ranch?
What do you produce here? Meat? Cheese? Fruits or vegetables? Anything else?
Do you have any alternative sources of income? If so, what are they?
How long do you plan on ranching?

About Cattle
How many cows do you have? Males? Females? Baby cows?
How big are your cattle on average? What's their birthing rate? Death rate?
Are your cows ever inside a stable of some sort? Are the wandering (i.e. no fence anywhere)?
What do you feed your cows? (grass, bales of hay, sugar cane, tree leaves, jicaro fruit, nutritional supplements)
Do you do any kind of rotation with your cattle and land?
How do your cows get water? (get additional water, are they traveling?)
How has the drought affected you? Are you doing anything differently due to the recent drought?
Do you have to treat your cattle for anything? Vaccines, antibiotics? What do you have to treat them for?
What are you biggest concerns as a cattle rancher? Water? Jaguars? Meat prices? Cattle health?

About Pasture
How do you consider the quality of your pasture?
What types of plants are in your pasture? (Looking for species or at least common names to help with ID)
How do you maintain your pasture? Do you use improved grass/silage? Do you sow grass?

If there is more available forested space
Why haven't you cleared that land?
If you clear that land for pasture would you leave trees? Why - size, cattle like them?

If there are trees
How did the trees on your property get here? Did you clear the forest yourself and leave some trees? Is there a certain amount of tree cover you like? (Maybe instead, "why did you leave these trees?")

Why do you still have trees on your ranch? Do you like them? Why do you like them? (I think if this is true, we'll get the answer in the previous question)
Do you notice benefits with the trees? Which trees? Do your cows act different around trees? Do you notice any behavior of your cattle with the trees?
Would you like to cut down all the trees on your pasture if you could?
Would you like to have more trees on your pasture? If so, why haven't you grown them?

If there are no trees
You have no trees on your pasture - why is that? Did you clear the forest yourself and cut them all? Did a storm come through? Was it the previous property owner and that's how the lot came?
Would you like to have trees on your pasture? If so, why haven't you grown them?

**In Spanish**

Hace cuanto tiempo que está en este rancho?
Usted es dueño o renta el rancho?
De qué tamaño es el rancho? De qué tamaño es el pasto?
Que se produce aqui? Carne? Leche? Frutas o vegetales? Madera?
Usted tiene algún otro forma de ganar dinero?
Por cuánto tiempo se planea quedarse aquí?

Sobre Vacas
Cuántas vacas tiene? Cuantos son machos? Cuántas son hembras? Cuantos son terneros?
Cuántas vacas nacen al año? Cuántas vacas se mueren al año?
De qué tamaño es la vaca al promedio?
Sus vacas están adentro de un establo algunos días o durante el dia? O siempre están por el pasto? Pueden vagar a donde sea?
Que le da de comer a sus vacas? Solo pasto o trigo, caña de azúcar, hojas de los árboles, jícaro, suplementos nutricionales?
Usted tiene algún tipo de rotación con sus vacas y el pasto?
Cómo obtienen agua suas vacas? Está aquí el agua o tienen que ir a un río o pasar por el bosque?
Como se ha afectado la sequilla? Está haciendo algo diferente por la sequilla últimamente?
Hay que tratar las vacas aquí con unas vacunas o antibióticos? Para que?
Que son sus preocupaciones más grandes de ser ranchero? La sequilla? Los jaguares? El precio de carne/leche? La salud de las vacas?

Sobre el Pasto
Como se considera la cualidad de su pasto?
Qué son las tipas de plantas en el pasto?
Como se mantiene el pasto? Usted usa paso mejorado? Se siembra hierba?

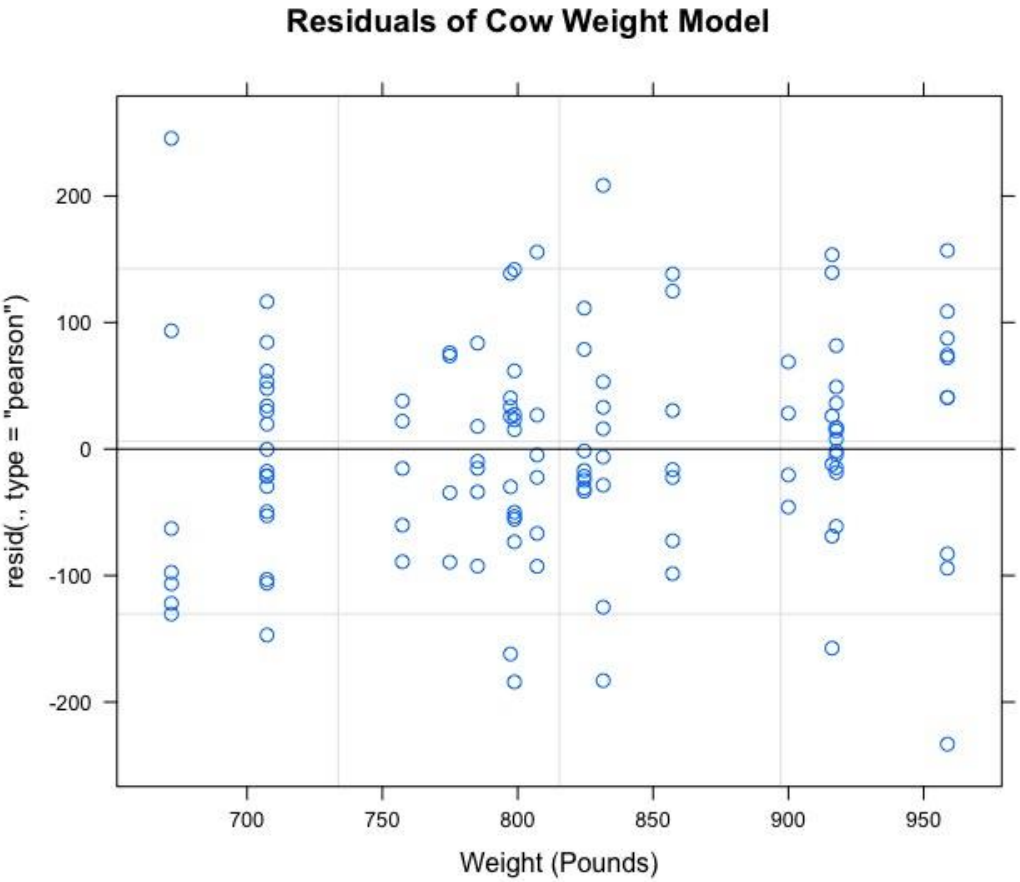
Si hay arboles
Cómo llegaron los árboles a su propiedad? Corto usted el bosque y dejo ciertos arboles? Hay alguna cantidad de area cuvierta por arboles que le gustaria tener? (Porque dejo esos arboles)

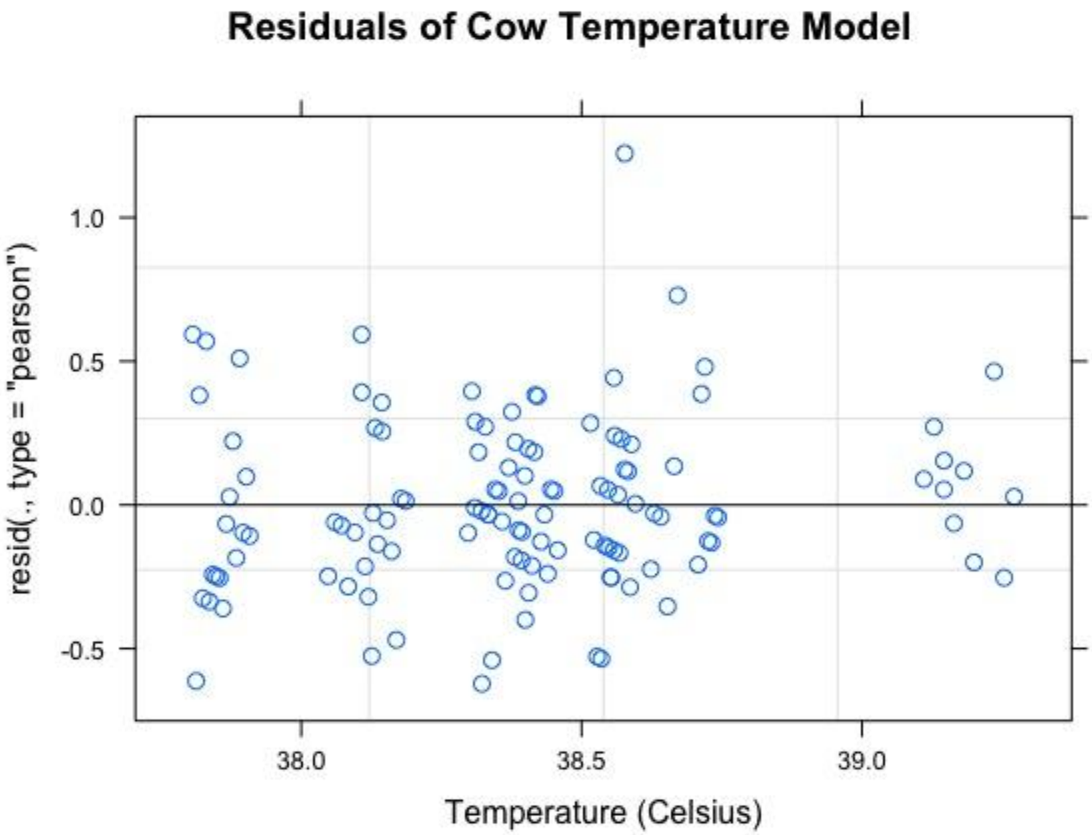
Porque todavia tiene arboles en su rancho? Le gustan? Porque le gustan?
Ha notado ciertos beneficios con los arboles? Que arborles? Ha notado algun tipo de comportamiento entre sus vacas con los arboles?
Le gustaría cortar todos sus arboles en el rancho si pudiera?
Le gustaría tener mas arboles en su pasto? Si si, porque no los ha crecido?

Si no hay árboles
Porque no tiene árboles en su pasto? Los corto usted? Hubo una tormenta? Asi estaba la tierra cuando usted llegó?
Le gustaría tener arboles en su pasto? Si si, porque no los ha crecido?

Si hay un bosque al lado
Porque no ha aclarado la tierra?
Si aclara la tierra para pasto, dejarla algunos árboles? Porque? Las vacas les gustan los árboles?

Appendix 6. Residuals of Cattle Weight and Cattle Temperature.




Residuals of Cow Temperature Model
resid(., type = "pearson")
1.0
0.5
0.0
-0.5
38.0
38.5
39.0
Temperature (Celsius)

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