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Rural Tree Decline in Tasmania's Midlands: Stand Structure, Substrate Geology, and Carbon Content Analysis

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Rural Tree Decline in Tasmania's Midlands:

Stand Structure, Substrate Geology, and Carbon Content Analysis

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Abstract

The once densely forested dry sclerophyll landscapes of the Midlands of Tasmania are now characterized by vast spans of agricultural pasture with intermittent dead and ailing eucalypt trees. This landscape changing phenomenon, rural tree dieback, has come into the focus of a collaborative research team at the University of Tasmania sponsored by the nonprofit organization, Greening Australia. Through the efforts of this team of scientists of diverse backgrounds, Greening Australia aims to create an ecologically viable reforestation plan for the Midlands.

I conducted a pilot study focusing on a 400 ha plot within the Dennistoun Farm property in Bothwell, Tasmania in which I analyzed stand structure and substrate geology for 8 transects selected for 4 different combinations of either forested or unforested land type and either sandstone or dolerite substrate. I also analyzed the effect of substrate type on elements of tree physiology for *Eucalyptus tenuiramis* and *Eucalyptus viminalis*, the dominant eucalypt species in the mixed species stands within the area of interest. Finally, I calculated the aboveground and soil carbon content and carbon dioxide sequestration for each land type and underlying geology of the 400 ha plot of Dennistoun property.

The 400 ha plot of Dennistoun Farm property is mostly composed of 248 ha of unforested landscapes and only 152 ha of forested landscapes. The forested landscapes on dolerite substrate sequestered the most CO_2 relative to total area. Mean SLA was significantly greater for individuals of the same species on sandstone substrate than on dolerite substrate for both *E. tenuiramis* and *E. viminalis* in forested landscapes but mean SLA was not significantly different between individuals of the same species but different geologies from unforested landscapes. The top 5 cm of soil was 4.72% carbon in the dolerite soil from a forested landscape. The data collection and analysis methodologies established for this pilot study will be expanded across the Clyde River catchment. The results of the continuation of study will be submitted to Greening Australia to aid in the creation and establishment of a forest regeneration plan, hopefully in the near future.

ISP Topic Codes: 608, 614, 620

Keywords: Rural tree decline, Carbon analysis, Midlands, Tasmania

Table of Contents

1. Introduction

2. Methodology

3. Results

4. Discussion

5. Conclusions

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Figures and Tables

Abbreviations

CSIRO: Commonwealth Scientific and Industrial Research Organization

DBH: Diameter at Breast Height

GIS: Geographic Information System

GPS: Geographic Positioning System

SLA: Specific Leaf Area

UTAS: University of Tasmania

1. Introduction

1.1 Overview of Tasmania's Climate and Forest Types

The island state of Tasmania is composed of a wide range of environmental conditions within its small area, harboring a diverse distribution of vegetation. Jackson declares Tasmania's "inherent variability of environment" yields at least one element of each season daily (2005). The Tasmanian Midlands, the region of focus for this study, is an inland region subject to rain-shadow from mountain chains both to the East and West (Jackson, 2005, p 16). Rainfall in this region takes the form of occasional light showers, though the rate of precipitation is greatly exceeded by the evaporation rate with a precipitation/evaporation ratio of approximately 0.5 (Jackson, 2005, p. 17). In the Midlands, average maximum temperatures are less than 10°C for two months at an altitude of 450 meters, with a decrease of 0.6°C per 100 meter increase in elevation (Jackson, 2005, p. 14).

The variations in altitude, water availability, and soil fertility create suitable conditions for communities falling in to three categories: Austral montane, temperate rainforest, and sclerophyll forest (Jackson, 2005, p. 1). The three broad vegetation groups can be further divided into seven distinct categories: temperate rainforest, wet sclerophyll, alpine and sub-alpine, dry sclerophyll, coastal, moorland or sedgeland, and cleared land (Jackson, 2005, p. 1), but the dominant vegetation types can cross from one category to another very quickly within small spans of land, making classification generalization necessary to some extent.

1.1.1 Dry Sclerophyll Forest

Dry sclerophyll forest covers 26.3% of Tasmania (Jackson, 2005, p. 4) and is the dominant vegetation of Tasmania's Midlands. Duncan and Brown (1985, in

Jackson, 2005) subcategorized dry sclerophyll forest communities by their understorey development: grassy, sedgey, heathy, or shrubby. These separate classifications illustrate the community responses to environmental factors including water availability, drainage, aeration, nutrition, fire frequency, grazing, and disturbance (Jackson, 2005, p.4).

Grassy woodlands are characterized by the nutrient rich igneous dolerite soil in low rainfall areas with good drainage (Jackson, 2005, p. 5). Sedgey forests or woodlands are predominately above clay-rich or sandy organic soils which have poor drainage and aeration yielding high water tables (Jackson, 2005, p. 5). Forests with heathy understory development indicate sandy soils with low nutrition levels and usually occur in locations with low rainfall and low fire frequency (Jackson, 2005, p. 5). Finally, shrubby understoreys are found in forests with plentiful water resources and good to moderate drainage (Jackson, 2005, p.5).

The dominant *Eucalyptus* stands of dry sclerophyll forests are typically single-species in Tasmania with clearly defined boundaries, but Reid and Potts (2005) write that “mixed stands” occurr in the coexistance of two or more species. In a mixed stand, a *Monocalyptus* subgenus species typically acts as the dominant species with a subdominant *Symphomytrus* species. Mixed stand structure is common in the Midlands.

1.2 Forest Degradation in Tasmania

Despite the rich forest dynamic in Tasmania, there has been a long history of forest degradation. Greater comprehension of the many historical and current causes of forest degradation will be necessary for the success of regeneration and conservation on both private and public lands.

1.2.1 Aboriginal Influence and European Settlement

Before European colonization, Aboriginal land use involved the use of regular, controlled bush fires. These fires restricted forest development on the nutrient rich, basaltic soils (Jackson, 2005, p. 5). These burns reduced the tree cover and left seedlings vulnerable to the growth preventative effects of frost and grazing (Jackson, 2005, p. 5).

European settlement and the following removal of Aboriginal people from Tasmania's Midlands resulted in an increase in livestock grazing, perpetuating the destruction of native herbs and *Themeda*, and promoting the growth of the "unpalatable" *Poa* and ending dry eucalypt regeneration (Jackson, 2005, p. 5).

1.2.2 Clearfelling for Logging Industry

Flanagan (2007) established clearfelling as the complete destruction of a forested landscape by the process of tree removal through the use of chainsaws and skidders followed by chemical-induced burning of the remaining debris. The burning portion of the clearfelling process causes ecosystems to lose important structures including hollow trees, fallen logs, semi-fire resistant understorey thickets and plants that play important roles in the ecosystems are destroyed or left present only in small quantities (McGhee, 2004). Following this land clearing technique, native 50-60 year old mountain ash forests are replaced with non-native plantations consisting of shining gum, blue gum, or pine species (McGhee, 2004). Replacing native forests with plantations leads to an overall decrease in biodiversity and threatens the sustainability of the logging industry (McGhee, 2004), which has been very influential on the Tasmanian natural environment and economy.

An argument in favor of clearfelling that McGhee (2004) addressed was that the cut and burn process "mimics" a natural large scale disturbance like a bush fire. This argument has been refuted by substantial scientific evidence indicating that the damage from clearfelling far exceeds that of natural fires (McGhee, 2004). Though the forestry industry has fallen "under siege" (McGhee, 2004), the reduction of logging would inevitably lead to job loss. Aging industry employees may not easily be trained for new, green collar jobs. While the logging industry remains successful and clearfelling remains a cost-effective forestry technique, this type of forest degradation will not subside.

1.2.3 Fire

Jackson (2005) indicates the "direct climate control" of forest growth has been mitigated by the prevalence of fire over the past 12,000 years (p. 13). Because of frequent firing in the Midlands, where the majority of fires are man-made instead of lightning-ignited, the open pasture and savannah has been maintained and unable to revert to its historical vegetation type, dry sclerophyll (Jackson, 2005, p. 14). However, sclerophyll forests are well adapted to survive fire. The dominant eucalypt trees regenerate after burns from "massive seed stocks" stored in subterraneous capsules (Jackson, 2005, p. 37). The high oil content and litter production, and low rates of litter breakdown actually promote and prolong fires in dry sclerophyll forests, but they typically have "fire-free" periods lasting 80-100 years (Jackson, 2005, p. 37).

1.2.4 Agriculture

The Midlands of Tasmania saw the onset of agriculture at the beginning of European settlement. The agricultural boom led to high levels of livestock grazing which had adverse implications for many aspects of the environment contributing to forest degradation (Yates, Norton, & Hobbs, 2000). Yates, Norton, and Hobbs (2000) found some of the forest characteristics associated with high grazing levels are decreases in perrenial native cover in favor of annual exotic cover and decreased litter coverage.

In addition directly effecting vegetation growth in dry sclerophyll landscapes, Yates, Norton, and Hobbs (2000) concluded that livestock grazing also negatively impacts the soil composition, resistance to erosion, and ability to absorb water. Davidson and Close (2002) found that soil desiccation has become increasingly problematic because the increasing coverage of nonnative species prevents water from penetrating the soil. Dry, nutrient poor soil is subjected to heightened erosion when it is exposed to wind when it is cleared and plowed for planting (Davidson & Close, 2002). To mitigate the effects of agricultural grazing, strategies involving resource capture and retention must be employed (Yates, Norton, & Hobbs, 2000).

1.3 Greening Australia's Reforestation Goal

Nonprofit organization, Greening Australia, aims to reverse forest degradation not only in Tasmania, but across the Australian continent. Their mission statement is "…to protect and restore the health, diversity and productivity of our unique Australian landscapes" (Greening Australia, 2007). Reforestation efforts that are not ecologically informed can prove to be unsuccessful and are not likely to provide lasting benefits. With the understanding that landscape restoration must involve thorough research, planning, and implementation stages, as well as a post-planting care regimen, Greening Australia has the potential to restore a variety of once forested landscapes.

Headed by Dr. David Bowman, and assisted by Lab Manager Scott Nichols and Research Fellow Lynda Prior, a long term research program has been established at the University of Tasmania to direct Greening Australia's efforts to increase the resilience of significant landscapes. Ultimately, Greening Australia hopes to promote resistance to the effects of climate change and use forests for carbon accounting (Greening Australia, 2007). The team, funded by Greening Australia and incorporating members of diverse backgrounds based in Hobart, aims to evaluate the incidence of rural tree decline in Tasmania's Midlands, focusing on the Clyde River catchment. Based on their findings, they will work with Greening Australia to create a viable reforestation plan for this area.

1.4 Description of Forest Specific to Clyde River Catchment

The Clyde River catchment, located in the Midlands of Tasmania, surrounds the rural town of Bothwell, approximately 100 km northwest of Hobart. Dominated by agricultural land subject to heavy grazing and plowing, this area was once a densely forested dry sclerophyll landscape. The dominant species found in the catchment's dry sclerophyll forests are *Eucalyptus tenuiramis* and *Eucalyptus viminalis* (Reid & Potts, 2005, p. 206). *E. tenuiramis* inhabits dry soils, typically mudstone and dolerite across the southeast of Tasmania. *E. viminalis* is frequently a subdominant species in dry habitats (Reid &Potts, 2005, p. 206). Other common eucalypt species in the catchment include *Eucalyptus pulchella* and *Eucalyptus* *pauciflora* in addition to many hybrid individuals exhibiting mixed traits of multiple species

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1.5 Incidence of Rural Tree Dieback in the Midlands

Recently, the phenomenon of rural tree dieback has plagued the degraded land as regeneration of native eucalypt trees has slowed. In addition to dead trees, presence of eucalypt trees with dead branches extending beyond apparently healthy foliage and new foliage and wood development from epicorms also indicate impending rural tree decline (Close & Davidson, Review of rural tree decline in a changing Australian climate, 2004). Close and Davidson (2004) have studied this pattern across Australia and specifically in Tasmania's Midlands. This area of Tasmania is now "devoid of trees" for reasons including "clearing for agriculture, senescence of old trees, premature tree decline," and the prevention of natural regeneration due to grazing (Close, Davidson, Churchill, & Corkery, 2010).

Close and Davidson (2002) establish that the tree deaths without subsequent regeneration that has occurred with increasing frequency in the past 30 years have negatively impacted stand structure by causing heightened levels of fragmentation through the isolation of ailing trees lacking native understorey. Due to the habitat fragmentation, which may be accentuated with the imminent onset of rapid climate change (Hughes, Cawsey & Westoby, 1996), regeneration efforts must occur at both "patch" and landscape levels (Yates & Hobbs, 1997).

1.5.1 Difficulties of Rural Forest Restoration

Yates and Hobbs (1997) concluded more than a decade ago that causes of rural tree decline have been established and the research focus must now shift toward creating a viable regeneration plan. Neil Davidson, University of Tasmania, and Dugald Close, Cooperative Research Centre for Sustainable Production Forestry (2002) have analyzed tree decline in the Midlands of Tasmania and continue to conduct research related to reforestation planning.

Close and Davidson (2002) wrote that many factors including competition, grazing, and low seed sets contribute to the difficulties of forest regeneration in rural areas. Reforestation efforts were most often plagued by a lack of management following the initial seeding sessions (Close & Davidson, 2002). Weed control and watering during the first year of growth were highly influential in the success of the reintroduced native species in the Midlands (Close & Davidson, 2002). Close and Davidson (2002) listed specific recommendations for reforestation in drought-prone areas such as the Tasmanian Midlands, but concluded that a variety of factors contribute to the success of reforestation depending on climatic and geographic features of different forests. Within the Clyde River catchment, specific conditions forest plots can be analyzed for these climatic and geographic features to increase the probability of achieving high levels of forest regeneration.

1.6 Quantifying Forest Health

The health analysis of the remaining forests within the Clyde River catchment will aid in the establishment of Greening Australia’s reforestation guidelines for Tasmania’s Midlands. There are different techniques to quantify various measures of forest health.

1.6.1 Stand Structure and Ground Cover Analysis

Davidson, et al., (2007) found that native ground cover consisting of shrubs, liter, moss, and lichen as opposed to “exotic pasture species” closely correlated to healthier trees composition in the corresponding canopy (p.439). Close and Davidson (2002) concluded that tree decline is increasingly severe with high levels of “native vegetation removal” and development of agricultural pastures. The onset of agriculture brought soil compaction, nutrient enrichment, competitive non-native pasture species, and understorey alteration (Close, Davidson, Churchill, & Corkery, 2010). By quantifying the stand structure and corresponding health in addition to the understorey compositon, the health of landscapes of different land types and substrates can be assessed.

Allometric relationships between dbh and biomass can be applied to the stand structure information to determine the total biomass and carbon content for designated areas of land. This information is valuable to Greening Australia’s goal of combining reforestation plans with carbon accounting (Greening Australia, 2007).

1.6.2 Tree Physiology: Specific Leaf Area

Specific leaf area (SLA) is a physiological measurement that is positively correlated with many other tree characteristics including photosynthetic capacity, dark respiration rate, and leaf N and P contents (Wright, et al., 2004). It is a useful measurement for modelling changes in vegetation, carbon, and nitrogen with land-use and climate change (Wright, et al., 2004).

Australian plant species typically have lower SLAs because of lower soil fertility and moisture (Wright, et al., 2004). Schulze, Turner, Nicolle, and

Schumacher (2006) established a positive correlation between δ ^{13}C and SLA that is "highly species and soil type specific." Wright et al. (2004) in *The worldwide leaf economics spectrum*, states that a nutrient rich soil, like the dolerite soil in the Midlands, will yield foliage with higher SLAs and nutrient poor soil, sandstone for example, will yield foliage with lower SLAs. Schulze, Turner, Nicolle, and Schumacher (2006) further concluded that variation in δ ^{13}C depends on general site conditions including fire history and degree of biodiversity.

1.6.3 Soil Analysis

According to Davidson et al. (2007), soil and understorey distinguished between healthy, declining, and poor stands under canonical analysis. Soil characteristics including soil nitrogen, pH, and organic carbon content accounted for 72% of tree health variation (Davidson, et al., 2007). The soil carbon content for a designated area of land can be calculated based on the nutrient percentages and bulk soil densities. Soil carbon is an important figure to take into consideration before commencing any forest management plans because it could greatly impact the success rates of reforestation.

1.7 Benefits of Forest Restoration for Carbon Trading

Forest clearing results in large quantities of carbon released into the atmosphere. Raison et al. (2009) determined that the biomass lost to forest clearing between 2006 and 2007 contained 8.6 million tons of carbon. This was a decrease from the 2005 to 2006 figure of 11.2 million tons of carbon (Raison, et al., 2009), likely due to a documented substantial decline in tree clearcutting in the same time period. According to the calculations of Raison et al. (2009), the biomass cleared from

2006 to 2007 will result in the release of 31.55 million tons of carbon. During conversion of forested land to agricultural land, carbon is also released from the soil in addition to the woody biomass.The conversion of land from forest to agricultural pasture or cropland results in a 10% loss in soil carbon in the top 30 centimeters (Raison, et al., 2009).

In addition to Greening Australia's broad goal of successful landscape restoration, the organization has an additional initiative of investigating carbon sequestration potential of forested landscapes for Australia's imminent carbon economy (Greening Australia 2007). The prevention of forest removal could stop millions of tons of carbon from being released. The establishment of new forested landscapes or the reversion of agricultural land, like that found in the Midlands, to the native forest that once dominated the landscape could sequester carbon that has been released from other sources.

1.8 Study Goals

The Dennistoun Farm property in Bothwell, Tasmania can be considered the site of a pilot study that will be expanded to different locations within the Clyde River catchment in Tasmania's Midlands. Through stand structure, ground cover, tree physiology, and soil nutrient analyses, a data collection and analysis protocol will be developed to determine the aboveground and belowground carbon contents of different land types on different substrates. Additionally, overall stand health will be quantified by substrate type based on stand structure and tree physiological measurements.

2. Methodology

2.1 Site Selection

The Clyde River Catchment surrounding the rural town of Bothwell in Tasmania's Midlands, 100 km northwest of Hobart, is the focus area for this study. I surveyed the entire Clyde River Catchment with University of Tasmania Lab Manager Scott Nichols, Professor David Bowman, Research Fellow Lynda Prior, and CSIRO representative Anthony O'Grady from April 7, 2010 to April 9, 2010. We visited 12 zones that University of Tasmania Honours Student, Rowan Harris, selected for varying climates and landscape settings using ArcGIS and imported maps from the Tasmanian Vegetation Mapping and Monitoring Program (TASVEG) database created by the Tasmanian Department of Primary Industries, Parks, Water and Environment.

From these 12 zones, Nichols and I chose to focus on the Dennistoun Farm property, about 10 km from the center of Bothwell, for its accessibility and varied land types and underlying geology. According to TASVEG, this property contains both dolerite and sandstone substrates beneath a combination of dry sclerophyll woodland and agricultural land (formerly dry sclerophyll woodland). Using the TASVEG topographic map, we created eight 100 meter transects along constant altitudes encompassing 4 different combinations of substrate and land types (Figure 2.1).

Figure 2.1 Map of the Dennistoun Farm property showing underlying geology and designated transects.

2.2 Data Collection

The data collection period spanned a three week period between April 12, 2010 and April 30, 2010. A series of field-based data collection sessions on Dennistoun Farm were interspersed with lab-based data collection at the University of Tasmania and CSIRO.

2.2.1 Field Data Collection

Using a handheld GPS unit, Scott Nichols and I located the start and end points for each of our eight 100 meter transects previously identified using ArcGIS overlays of TASVEG maps. Prior to commencing stand structure data collection, we defined a tree health scale by taking exemplary pictures of trees of varying health rankings on a scale of 0, indicating a dead tree, to 5, indicating a tree of pristine health (Appendix 1).

To begin data collection at each transect, we completed a preliminary tree count and selected a transect width to incorporate 50 trees. In the more intensively managed landscapes, there were fewer than 50 trees in close proximity to the centers of transects, in which case the transect width was set to a 20 meter maximum. Transects in densely forested landscapes had widths of 5 to 10 meters.

2.2.1.1 Transect Data Collection: 20 Meter Intervals

For each transect, Nichols and I recorded underlying geology, land type, aspect, and slope, of each transect as well as dominant vegetation types and evidence of any disturbances. We used a 100 meter tape to designate the six 20 meter intervals (0 m, 20 m, 40 m, 60 m, 80 m, 100 m) at which we would analyze ground and canopy cover and collect soil samples. We quantified ground cover along the 20 meter intervals by completing a layered estimate of coverage percentage within in 1 meter radius circle of each of our 10 predetermined categories: bare ground, rock, grass, other graminoids, lomandra, forbs, shrubs, cryptogams, leaf litter, and scats. Using a densitometer, we estimated the amount of canopy coverage at each interval.

At the 20 meter intervals, Nichols and I collected soil samples at depths of 0-5 cm, 5-10 cm, 10-20 cm, and 20-30 cm using a split core sampler in the softer, sandstone substrate and digging through the harder, dolerite substrate with a pick and shovel. We bagged and labeled these samples and refrigerated them until they could be processed for nutrient content.

2.2.1.2 Transect Data Collection: Stand Structure

For each tree within each transect's predetermined width, Nichols and I recorded the tree's species and location in meters along the transect and from the center of the transect. We measured the height and dbh of each tree using a hypsometer and dbh tape or calipers, respectively. To quantify the overall health of each tree, we used the photographically documented scale ranging from 0, dead, to 5, pristine health.

We recorded length and diameter of any coarse woody debris crossing the center of each transect with a diameter of more than 3 cm. Debris with a diameter of less than 3 cm was excluded from data collection for carbon analysis because its relative carbon content is very low. Finally, we recorded the height of any seedlings present within 1 meter on either side of each transect (Appendices 2, 3).

2.2.1.3 Tree Physiology

Nichols and I collected foliage and wood samples from the dominant *Eucalyptus* species in the area surrounding one transect of each land use and substrate type, remaining within the geologic and land type and boundaries defined by TASVEG. Using extendable pruning poles, we clipped the foliage and wood samples from the northern side of each tree. Each sample consisted of 10 to 15 leaves, depending on individual leaf sizes, and a wood segment approximately 5 centimeters long and no more than 2 centimeters in diameter. We refrigerated these samples in plastic bags until they could be analyzed for specific leaf area and wood density at UTAS and CSIRO labs.

For each tree from which Nichols and I collected leaf and wood samples, we measured the height using a hypsometer, the dbh using dbh tape or calipers, and health on the scale of 0-5. We also quantified reproductive health of each tree based on presence of flowers, buds, and capsules. We used 0 to indicate no flowers, buds, or capsules, 1 to indicate some, and 2 to indicate many (Appendix 4). We took a picture of each tree and marked the GPS coordinates in the handheld GPS unit.

2.2.2 Lab Data Collection: Specific Leaf Area and Wood Density

At the CSIRO lab facilities, I used a RHIZO scanner and its accompanying software to measure the total area of each foliage sample. I measured the dry mass of each sample using a beaker on a tared digital scale after drying the samples in an oven at 65 °C for 48. To calculate the specific leaf area (SLA), I divided each sample’s leaf area by its dry mass (Appendix 4).

To calculate wood density I recorded the diameter of each wood sample at the point of excision using digital calipers. I removed the bark from each sample and found the volume by piercing each wood sample with a needle and submerging it just below the surface of the water in a beaker on a tared scale. This displacement method of measuring wood volume follows Phytagora's theorem, under which 1 gram of water = 1 cm^3 of water because water has a density of 1(Figure 2.2). The weight given by the scale is therefore equivalent to the volume of the wood sample. After the wood samples dried for 48 hours in an oven at 90 °C, I took the mass of each sample (Appendix 5).

Figure 2.2 Illustration of water displacement method of measuring wood volume following Phytagora's theorem (Chave, 2005).

2.2.3 Lab Data Collection: Soil Nutrient Content

To prepare the soil samples for nutrient content analysis, I removed all fine woody debris from the soil by first filtering each sample through a 2 millimeter sieve and then sorting through each sample using forceps. I standardized the debris removal process by allotting 2 minutes of sorting for each soil sample.

The samples had to be homogenized and reduced to an appropriate grain size for analysis using a soil grinder. The grinder has two canisters, each of which I filled half way with a different soil sample and added two metal grinding balls. I programmed the grinder to shake the canisters for 20 seconds. When the samples were finished grinding, I transferred a small amount of the ground soil sample to a glass vial for storage using a small, plastic weigh boat.

The soil nutrient analysis machine, the CHNS/O Analyzer, processes the samples by burning 14 to 30 milligram quantities in combustible tin capsules at 950° C. I transferred a small quantity of soil from each ground sample containing vial in to a tin capsule using a scoopula and folded over the top of the capsule with forceps. After I weighed each sample on a tared electronic scale to confirm it was within the analyzable range, I pressed the capsule in to a small circle. I then reweighed each wrapped sample and recorded the mass (Appendix 6).

2.2.3.1 CHNS/O Analyzer Calibration and Processing

The analysis machine requires calibration before it can accurately process soil samples. To calibrate the machine, I ran a sequence of two blanks, empty tin capsules, followed by a standard, a 2 to 5 milligram sample of acetanilide, then by two calibration 2 to 5 milligram samples of acetanilide, one final standard, also a 2 to 5 milligram sample of acetanilide, and a final blank tin capsule. If this calibration sequence does not result in a carbon content within 0.5 of 17.1 % for the final standard, either the same sequence must be repeated, or a different calibration sequence must be run through the machine until calibration is achieved.

Once the machine is calibrated, each sample is loaded in to tray on the machine in a numbered auto-run position, corresponding to the labeled slot in a storage container documented on the lab proforma (Appendix 7). The machine can process 50 samples in one run, lasting 3 to 4 hours. The output is in the form of a data table which gives the soil carbon, hydrogen, and nitrogen content in the form of percentages.

2.3 Data Analysis

The majority of my field data collection process will serve as a pilot study for similar or identical data collection across the Clyde River Catchment. I summarized the stand structure and ground cover data and looked for trends based on land type and underlying geology using Microsoft Excel. I also used the stand structure data collected for each transect to establish an estimate of the aboveground carbon content of the Dennistoun Property. To compare the effects of different substrate types on tree physiology, I used the foliage and wood samples from varying substrate and land use types. Finally, I used the soil nutrient content to calculate the below ground carbon content at different depths.

2.3.1 Establishment of Aboveground Carbon Content

To calculate the above ground carbon content of the 400 hectare (4 km^2) section of Dennistoun Farm property I organized the transect data into four categories: forested dolerite, unforested dolerite, forested sandstone, and unforested sandstone. I used the allometric relationship of measured dbh of trees along each transect to their aboveground biomass. This relationship varies based on many factors including tree and substrate type.

2.3.1.1 Application of Allometric Relationship

For the Dennistoun eucalypt dominated landscape, I used four different equations, two created based on samples from nutrient-rich dolerite substrate, and two created based on samples from nutrient-poor sandstone substrate. Within each substrate classification, I used one equation for general aboveground biomass, which I applied to standing trees, and one equation specific to branches, which I applied to coarse woody debris.

Table 2.1 Allometric equations relating dbh to biomass in dry sclerophyll forests on different substrates (Keith, Raison, & Jacobsen, 1997).

I averaged the aboveground biomasses of the transects with corresponding land use and substrate geologies to yield average aboveground biomasses for each category. Aboveground carbon content is estimated at 50 percent of the aboveground biomass, so I multiplied each of the average aboveground biomasses by 0.50. To calculate CO_2 sequestration, I multiplied the carbon content values by the conversion factor of 3.6663, the ratio of CO_2 to C determined by atomic mass.

2.3.1.2 Extrapolation to Dennistoun Property

To apply the aboveground carbon estimates to the entire 4 km^2 plot of Dennistoun Property of interest, I had to estimate the proportion of land that is forested and unforested on both dolerite and sandstone substrates. I defined the underlying geologies of the 4 km^2 section of land using ArcGIS and TASVEG, but I was unable to use the TASVEG land cover data because its categorization is too broad for small sections of land. Instead, I used ArcGIS to generate regular points at 20 meter intervals over the Dennistoun property (Figure 2.3).

Figure 2.3 Map of 4 km^2 section of Dennistoun Farm property showing substrate type, transects, and generated regular points used for classification.

By splitting the property in to 100 sections, each containing 100 points, I approximated the number of dots falling on of forested land and those on unforested land for dolerite and sandstone substrates. Using these dot counts, I calculated the proportion of forested and unforested Dennistoun land by underlying geologies. I applied the carbon contents I calculated for each land cover category to the Dennistoun property.

2.3.2 Specific Leaf Area and Wood Density

To compare the effects of landscape setting and underlying geology on the specific leaf areas of the *Eucalyptus* species within the Dennistoun Farm property, I grouped the samples by species. For the *E. viminalis* and *E. tenuiramis* species, I created a pivot table in Microsoft Excel to focus on the tree species, landscape setting, and underlying geology. I then used two 2 tailed t-tests to analyze differences in mean specific leaf areas of *E. viminalis* and *E. tenuiramis* on dolerite substrate to those of the same species on sandstone substrate within the same land type categories of forested or unforested.

I chose not to analyze wood densities at this time because of time constraints, but UTAS has a copy of the lab proforma and may decide to further analyze wood density in the continuation of this study.

2.3.3 Soil Fertility

To assess the nutrient content of the soil on the Dennistoun Farm property, I calculated the bulk soil density of 5 representative transects, covering each land use and substrate type. I dried the soil cores at 90°C for 48 hours and then weighed them in their 0-5 cm, 5-10 cm, 10-20 cm and 20-30 cm divisions. The volume of the soil samples from 0-5 cm and 5-10 cm was 98.17 cm^3 and the volume of the soil samples from 10-20 cm and 20-30 cm was 196.35 cm^3. I calculated the density by dividing the dry mass by the volume for each core.

I used the outcome of the soil analysis for forested landscape of dolerite substrate from the CHNS/O Analyzer to calculate the average soil carbon content at each of the four depths sampled using the measurements from the five 20 meter intervals. Based on the machine generated carbon content figures, I calculated the amount of carbon in metric tons in the Dennistoun property.

Due to prolonged difficulty with calibration, I was unable to measure the nutrient content of the sandstone soil samples. UTAS is storing the sandstone soil samples and intends to analyze the nutrient levels and apply the results to the Dennistoun property to calculate the total carbon content at each depth interval for each land type and substrate classification.

3. Results

3.1 Stand Structure Analysis

Stands chosen for analysis were composed of various TASVEG defined land cover and substrate classifications; each transect had its own distinct demography. Transects on both dolerite and sandstone substrates types had wide ranges of height distribution achieving a maximum heights of 24 meters on sandstone and reaching 30 meters in height on dolerite substrate (Figure 3.1). Though the tallest measured individual was on dolerite substrate, overall the stands on dolerite substrate had a smaller mean height (10.90 m ± 0.56 m) than the stands measured on sandstone substrate (15.9 m ± 0.56 m) ($t (241) < 0.0001$, $p < 0.05$).

Figure 3.1 Measured tree heights (m) of individuals within the dimensions of transects completed on sandstone and dolerite substrates.

Based on the data collected from transects on the Dennistoun property, the dolerite substrate had many more dead trees than the sandstone substrate. The average health of the trees from the sandstone transects including the measurements of the dead trees (1.71 ± 0.12) was significantly greater than the average health of the trees surveyed on the dolerite transects (1.35 ± 0.13) ($t\ (232) = 0.02$, $p < 0.05$). However, when the dead trees were excluded from analysis there was no significant difference between mean tree health on sandstone (2.32 ± 0.10) and dolerite (2.51 ± 0.11) substrates ($t\ (144) = 0.21$, $p < 0.05$).

Figure 3.2 Health of trees of sandstone and dolerite substrates according to documented photographic scale ranging from 0, dead, to 5, pristine health.

3.2 Dennistoun Farm Land Estimations

The totals of the regular points generated using ArcGIS for each of the four land type and substrate categories yielded the respective proportions of the 400 hectare plot of Dennistoun Farm property (Table 3.1). The highest proportion of land was unforested (agricultural) landscape on a dolerite substrate (191.08 ha), accounting for approximately 48% of the 400 hectare area of interest. The lowest proportion of land was unforested landscape on a sandstone substrate (56.80 ha). The forested landscapes on dolerite (81.04 ha) and sandstone (71.08 ha) fell between the two extremes, but their combined area accounted for only approximately 38% of the total area.

Table 3.1 Area of Dennistoun property classified by substrate and land type (ha)

3.2.1 Application of Allometric Relationships

The aboveground biomasses for each transect varied based on the number and size of trees found along the transect and the amount of coarse woody debris found intersecting the transect (Table 3.2). Dennis 1 had the greatest aboveground biomass (337.80 t/ha) despite having only 3 trees. The average dbh of the 3 trees along this transect was 147.33 cm (refer to Peter Brennan, SIT for disk with complete data set). The transect with the lowest aboveground biomass was Dennis 2 (133.99 t/ha). Dennis 2, the transect with the lowest aboveground biomass, was on a forested landscape while Dennis 1, the transect with the highest aboveground biomass, was on an unforested landscape.

Table 3.2 Aboveground biomass and carbon content (t/ha) by transect.

The average carbon content figure of each transect type was applied to the corresponding land type and substrate classification proportions of the Dennistoun Farm property (Table 3.3). The total aboveground carbon content of the 400 hectare section of Dennistoun Farm was 43,195.77 metric tons. This value corresponds to a total CO_2 sequestration of 158,368.66 tons. The unforested land on dolerite substrate, the land type and substrate classification with the greatest area (Table 3.1) and aboveground biomass per hectare (Table 3.2), accounted for the largest portion of

CO_2 sequestration. Forested land on dolerite substrate was responsible for more than twice as much CO_2 sequestration (40810.68 t) than forested land on sandstone substrate (19084.34 t) despite a small difference in total area between these two classifications (Table 3.1).

Table 3.3 Dennistoun property carbon content and total CO_2 sequestered by land type and substrate classifications (t).

Across the entire 400 hectare section of Dennistoun property of interest, the carbon content was 107.99 t/ha and the CO_2 sequestered was 395.92 t/ha.

3.3 Specific Leaf Area

In unforested landscapes, formerly dry eucalypt woodlands, the mean SLA of *E. tenuiramis* on dolerite substrate (47.91 cm^2/g ± 0.84 cm^2/g) was not significantly different than that of *E. tenuiramis* trees on sandstone substrate (45.03 cm^2/g ± 3.79 cm^2/g) ($t(10) = 0.58$, $p < 0.05$). Similarly, *E. viminalis* mean SLA of samples collected from dolerite substrate (47.77 cm^2/g ± 1.37 cm^2/g) were not significantly different than those collected of the same species from sandstone substrate (44.94 cm^2/g ± 2.18 cm^2/g) ($t(10) = 0.30$, $p < 0.05$) (Figure 3.3).

Figure 3.3 The mean SLA of *E. tenuiramis* and *E. viminalis* did not vary by substrate type in former woodland landscapes ($t\ (10) = 0.58$, $p < 0.05$), ($t\ (10) = 0.30$, $p < 0.05$).

In forested, dry eucalypt woodlands, the mean SLA of *E. tenuiramis* on dolerite substrate (47.07 cm^2/g ±1.76 cm^{2}g) was significantly less than the mean SLA of the samples of the same species collected from sandstone substrate (60.03 cm^2/g ± 2.39 cm^{2}g) ($t\ (9) < 0.01$, $p < 0.05$). Likewise, the mean SLA of *E. viminalis* samples collected from dolerite substrate (47.15 cm^2/g ± 2.02 cm^2/g) was significantly less than the mean SLA of samples of the same species collected from sandstone substrate (60.28 cm^2/g ± 2.43 cm2/g) ($t\ (13) < 0.01$, $p < 0.05$) (Figure 3.4).

Figure 3.4 In dry eucalypt woodland landscapes, the mean SLA of *E. tenuiramis* and *E. viminalis* differed by substrate type ($t (9) < 0.01$, $p < 0.05$), ($t (13) < 0.01$, $p < 0.05$).

3.4 Soil Nutrient Levels

The average carbon percentages decreased with depth of soil sample from 4.79% C at 0-5 cm to 0.86% C at 20-30 cm in the soil from the forested, dolerite transect (Table 3.4). The greatest decrease in mean soil carbon was between the uppermost sample, 0-5 cm, and the second depth, 5-10 cm.

Table 3.4 Average percent carbon at each depth of soil sampled for forested land on dolerite substrate.

The total soil carbon for the forested landscapes on dolerite substrate decreased as sample depth increased despite increasing total soil volumes calculated according to the respective bulk soil densities (Table 3.5)

Table 3.5 Soil volumes and carbon contents at 4 depths for forested land on dolerite substrate.

4. Discussion

4.1 Stand Structure

The smaller average height of the trees measured within dolerite transects can be accounted for by the young *Acacia* growth. This new growth is indicative of a transition from the eucalypt dominated dry sclerophyll landscape. The presence of new growth is important in the degraded landscapes of Tasmania's Midlands, but the lack of eucalypt seedlings along the transects completed in forested landscapes could be a preceding characteristic of forest structure change. Though many degraded agricultural landscapes have high protential for natural regeneration of eucalypt species, this potential is heavily dependent on management actions (Dorrough & Moxham, 2005).

The high tree counts of eucalypt individuals with health ratings of 0 (dead) on the dolerite substrates exemplifies rural tree dieback (Close & Davidson, Review of rural tree decline in a changing Australian climate, 2004). The high proportions of dead trees alters the overall mean health of these stands, but when the dead trees are excluded from analysis, there is no difference in visually quantified tree health on dolerite and sandstone substrates. The nutrient levels of these soils within the Dennistoun property may not actually be significantly different, but typically dolerite substrates have higher nutrient contents than sandstone substrates (Seymour, Green, & Calver, 2007). Further analysis of soil carbon and nitrogen levels could contribute to the analysis of the effect of substrate type on stand structure.

4.2 Use of TASVEG Maps to Categorize Dennistoun Farm Property

The Dennistoun Farm property composition reflects its stated designation of a farm land. The majority of the land included in the 400 ha plot has been cleared for agriculture since European colonization. The small proportion of remaining forested land may not remain that way for long, as Gunn's Ltd. has negotiated a deal with the property owner to commence forest management. This threat of native forest removal and replacement by plantation makes the documentation of the current aboveground carbon an important project. The current aboveground carbon content and sequestration figures can be compared with measurements taken following plantation establishment. It may be too late to preserve the native dry sclerophyll forest remaining on the Dennistoun property, but this study site can be used to exemplify the before and after of intensive forestry.

To estimate the proportion of the Dennistoun property falling in to each of the land type and substrate classifications, I had to rely on Tasmanian Department of Primary Industries TASVEG maps. Although these maps are incredibly useful, they were created for the entire state and are more useful for larger scale analysis than for the small scale on which I focused. Additional field-based verification of the TASVEG maps would assist the creation of more accurate land categorizations.

4.3 Use of Allometric Relationships to Estimate Aboveground Carbon Content

The use of allometric relationships to calculate aboveground biomass is incredibly useful, but to achieve high accuracy in estimations, many different equations must be employed. I completed simplified calculations, using equations Keith et. al. created based on dry sclerophyll forests on high nutrient dolerite substrate and low nutrient sandstone substrate. I also did not differentiate between live and dead trees measured because I did not record the number of years since the trees died, which is necessary to use equations specific to dead trees. Furthermore, some of my measured dbh values, particularly on Dennis 1, which had the highest aboveground biomass but only three individual trees, extended beyond the range of dbh values Keith, Barrett, and Keenan (2000) used to create the allometric equation. Because of the exponential nature of the allometric relationship, the resulting aboveground biomass estimates for the trees with large dbh values were very high. To more accurately estimate the aboveground biomass of the trees with large measured dbh values, an allometric equation that was created based on a wider range of data values should be used.

The large difference in the aboveground carbon contents of the forested landscapes on dolerite and sandstone substrates could be a result of the differing stand structures. The forested land on dolerite substrate is more densely covered with growth than its sandstone counterpart. Higher nutrient levels in the dolerite substrate may also correspond to increased vegetation growth and CO_2 sequestration, but soil nutrient analysis is necessary to verify the suggested higher nutrient content.

4.3.1 Value of CO_2 Sequestration

Because I did not calculate the annual CO_2, I cannot place a dollar value on the annual CO_2 sequestered in the Dennistoun property. The total CO_2 sequestered by the Dennistoun property would be worth almost $4 million based on a value of $25/t of CO_2, which is at the lower range of proposed prices based on a South Australian CSIRO report (Crossman, Summers, & Bryan, 2010). The higher the CO_2 sequestration figures, the greater the economic gain to the property owners. Based on the findings of this study, since the CO_2 sequestration figures from forested landscapes on dolerite soil are so much higher than forested landscapes on sandstone soil, reforestation efforts on dolerite substrate would be most successful in terms of stand health and economic profit.

4.4 Specific Leaf Area

Recalling that Wright, et al. (2004) wrote that high soil nutrient levels correlated positively with SLA, the significant difference in mean measured SLA between individuals of the same species, *E. tenuiramis* or *E. viminalis*, on dolerite and sandstone substrates within the forested Dennistoun property is particularly interesting (Figure 3.4). Though the literature established trend would create an expectation of a higher mean SLA on the nutrient rich dolerite substrate, the demonstrated trend is the exact opposite with a significantly higher mean SLA calculated from the individuals of the same species measured from nutrient poor sandstone substrate.

Another remarkable trend is the lack of a significant difference between the mean measured SLAs of *E. tenuiramis* and *E. viminalis* foliage samples from different substrate geologies within the unforested land of the Dennistoun property (Figure 3.3). Furthermore, the lack of a difference between the *E. tenuiramis* and *E. viminalis* mean SLA measurements is interesting because SLA is a measurement that should differ by species, but does not based on our findings.

A possible explanation for the deviation from the accepted relationship between SLA and soil nutrients is that the sandstone and dolerite soils on the forested portion of the Dennistoun Farm property do not have large differences in nutrient levels. The CHNS/O Analyzer results for soil carbon, hydrogen, and nitrogen levels could assist the analysis of why the results of the SLA analysis based on substrate type did not follow the widely documented relationship.

4.5 Soil Carbon

The soil carbon content of the dolerite soil from a forested landscape is relatively high. Dolerite soil is typically very nutrient rich, particularly in forested landscapes where the soil organic matter is influenced by the presence of leaf litter and woody debris (Seymour, Green, & Calver, 2007). The soil closer to the surface contains the most carbon, which is why agricultural development involving soil tillage leads to the release of large quantities of soil carbon to the atmosphere. Although I was not able to analyze the nutrient content of soil collected from sandstone substrate, sandstone typically contains less carbon than dolerite. If land must be plowed for agriculture, the use of sandstone soil instead of dolerite soil would mitigate the carbon release. However, the nutrient rich dolerite soil is probably preferable for maximizing agricultural yield.

Soil carbon content in metric tons is much lower than aboveground carbon content for the same landscape and substrate type. For a forested landscape on dolerite soil, the total soil carbon content of the top 30 cm, approximately 2,500 t, is much less than its corresponding aboveground carbon content of more than 11,000 t. The maintenance of healthy forested landscapes is more important in terms of carbon sequestration, but the maintenance of healthy forest would likely contribute to soil health maintenance.

5. Conclusions

5.1 Summary of Main Findings

The multifaceted issue of forest use and degradation has plagued Tasmania for decades. The phenomenon of rural tree decline has been studied for causation and some remediation techniques have been proposed, but the problem persists. The sparsely distributed native dry sclerophyll forest remaining in these degraded lands is under threat from the unsustainable forestry practices of the logging industry. A sustainable reforestation plan that is site and landscape specific and considers the established recommendations must be implemented as soon as possible.

The stand structure analysis and carbon budget established for the Dennistoun Farm property in Bothwell is a good evaluation of the remaining dry sclerophyll forest typical to the agriculturally-dominated Midlands of Tasmania. The calculation process of aboveground and soil carbon contents has some noted potential sources of error, but the figures are still valuable to establishing proportional land type and substrate type contributions to the total carbon values. Further stand analysis involving dating trees within stands of interest and selection additional allometric equations following more specific species classifications and incorporating the height and age of the trees would yield more accurate numbers for carbon accounting.

5.1.1 Pilot Study Success

One major success of this study is as a pilot study for Greening Australia's forest regeneration research. The establishment of a concrete methodology and creation of the necessary proforma for ground cover and stand structure data collection is substantial progress toward the overall goal of creating a viable reforestation plan. With the additional data that will be collected across the climatic and altitudinal gradients of the Clyde River catchment, further, more detailed stand structure comparisons can be completed. The type of data that has been collected further analyzes rural tree dieback and aims to establish a connection between quantifiable traits, including specific leaf area, and other environmental factors including substrate geology.

5.2 Continuation of Research

The University of Tasmania will continue to conduct field-based data collection across the Clyde River catchment. The same methodologies and field and lab proforma will be used for the additional data collection and analysis. This expansion of the cumulative data set will enable the research team to determine if trends established in the Dennistoun Farm plot are consistent or by what factors they vary across the Clyde River catchment. By expanding the data collection to areas subject to different environmental conditions along a continuous gradient, further comparison and analysis can be made between plant physiology and land use and substrate types. With some more time for data collection and analysis at UTAS and CSIRO, the Hobart-based research team will be able to help Greening Australia create a viable reforestation plan for Tasmania’s Midlands.

5.3 Recommendations for Further Study

A historical evaluation of land use change since European colonization, tracking the human-induced and natural alterations in forest composition could contribute significantly to the Greening Australia reforestation plans. Using aerial photography when possible and geo-referenced historical maps otherwise, ArcGIS could be used to analyze how land cover has changes. Further analysis could be conducted to determine where the most severe land cover changes occurred and what caused these changes.

Based on the findings of the UTAS and Greening Australia research team, a pilot study could be created to test the suggested reforestation regime before its widespread implementation. The results of this small-scale study could be used to verify that the maximum levels of success will be achieved through the proposed plan, avoiding wasted financial resources and potential land degradation from failed reforestation attempts.

Some landowners within the Clyde River catchment have initiated relatively small scale forest regeneration projects. Many of the properties in the Midlands have been owned and managed by the same families for decades, and the landowners therefore have great knowledge of the land. These people could be extremely valuable references for UTAS and Greening Australia. With landowner permission, the UTAS and Greening Australia research team could complete stand structure, tree physiology, and soil nutrient analysis over the next few years. These regenerative plots can be tracked over time for vegetative success. In the more distant future, assuming some of these privately owned plots experience high levels of reforestation success, they could be carefully analyzed for the factors most significantly contributing to the high success rates.

With the continuation of the ecologically informed contributions to the reforestation goals of Greening Australia, the hope for the future of Tasmania’s dry sclerophyll Midlands has promise. The more informed landowners become about the causes and effects of rural tree decline, the more likely they may be to resist the promised financial benefits of allowing forestry in favor of the long term health and viability of their land.

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