The Caribbean Pine (*Pinus caribaea* var. *bahamensis*): monitoring and ecology, in the Turks and Caicos Islands.

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List of Acronyms

ANOVA	Analysis of Variance
BRAHMS	Botanical Records and Herbarium Management System
CBD	Convention on Biological Diversity
CITES	Convention on International Trade in Endangered Species
COP	Conference of the Parties
CPRP	Caicos Pine Recovery Project
DBH	Diameter at Breast Height
DECR	Department of Environment and Coastal Resources
GPS	Global Positioning System
GSPC	Global Strategy for Plant Conservation
IAS	Invasive Alien Species
JNCC	Joint Nature Conservation Committee
PMP	Permanent Monitoring Plots
RBGK	Royal Botanic Garden Kew
TCI	Turks and Caicos Islands
TCNT	Turks and Caicos National Trust
UKOT	UK Overseas Territory
UN	United Nations

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Abstract

The Caicos Pine Recovery Project is working towards the recovery of the Caribbean pine from the devastating effects of the invasive scale insect, *Tourmeyella parvicornis*, and to ensure the survival of the Turks and Caicos pineyard habitat.

Research into invasive scale insect control treatments was initiated last year by the establishment of permanent monitoring plots across three islands, North Caicos, Middle Caicos and Pine Cay. This study presents the results of first year monitoring.

The assessment of three treatment types shows none to be effective as a control mechanism for the invasive scale insect. It is determined that the broadleaf clearance treatment significantly increases mean scale infestation and level of sooty mould, at a greater rate than the two alternative treatments.

Population estimates of the Caribbean pine were calculated from pine density data. The total number of live pines across all three islands is almost 735,000, with a decline of 57.5% due to the invasive scale insect. Of the live pines 96.6% are immature, suggesting the need for fire management and regulation of local fire use.

The effects of the Caribbean pine on the surrounding plant community are established. It is inferred that all pine has an influence on species composition in Middle Caicos, but this was only significant for the influence of the density of dead pines on five plants species. An increasing number of dead pines also negatively affect species richness.

Through this study it has come to light the need for further research to gain a comprehensive understanding of the pineyard ecosystem and the influence of the effects of the invasive scale insect and the consequential decline in pine numbers.

This study suggests recommendations for conservation and highlights the need for integrated and multi-disciplinary management strategies to ensure the effective and long-term conservation of the Caribbean pine in the Turks and Caicos Islands.

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1. Introduction

1.1 The Caribbean: a Biodiversity Hotspot under Threat

The Caribbean is a geographical region identified as a global biodiversity hotspot and a high priority for conservation (Myers *et al.*, 2000; Mittermeier *et al.,* 2004; Fa and Funk, 2007). Considered as a distinctive phytogeographic unit within the Neotropics (Gentry, 1982), current estimates state the Caribbean has 11,000 native plant species. Of these almost 8,000 are endemic to one or more of the archipelagos (Smithsonian National Museum of Natural History; Myers *et al.,* 2000; Santiago-Valentin and Olmstead, 2004), totalling 2.3% of the worlds endemic plant species. In addition to species diversity the region compromises high habitat diversity, consisting of 28 World Wildlife Fund terrestrial ecoregions (Torres-Santana *et al.,* 2010).

According to Myers (2000) only 11.3% of primary vegetation in the Caribbean remains, the main causes of declines being habitat reduction and destruction, usually for agriculture and development, climate change, fire, increasing hurricane intensity, unsustainable harvesting and invasive alien species (Torres-Santana *et al.,* 2010). The Caribbean has many threatened habitats, one of which is the pine rocklands of the Bahamas archipelago (Mills, 2008) on which this study is focused. The small extent of the Tropical Coniferous Forest ecoregion and anthropogenic pressures from development mean that the pine forests of the Bahamas and Turks and Caicos Islands are a highly threatened habitat type (World Wildlife Fund Ecoregion Profile: Bahamian Pine Forests) and are classed as critical/endangered by WWF Scientific Report (2001).

1.2 Caribbean Pine and Pineyard Habitat: the Need for Conservation

The Caribbean pine, *Pinus caribaea* var. *bahamensis* (Griseb.) W.H.Barrett & Golfari, characterises the pine rockland habitat in the Bahamas archipelago, as the only canopy species in an ecosystem of rocky, limestone soils. As the dominant species the presence of the Caribbean pine supports a diverse herb layer and an understory consisting of palms and hardwood shrubs (Myers, Wade and Bergh, 2004). The pineyards are present on only seven islands in the Caribbean, four in the Bahamas (Abaco, Andros, Grand Bahama and New Providence) at the North of the archipelago and three in the Turks and Caicos, in the very south (Pine Cay, Middle Caicos and North Caicos).

The Caribbean pine, is the national tree of the Turks and Caicos Islands (TCI), locally known as the Caicos pine, and is endemic to the Bahamas archipelago. It is the dominant species in the pineyard ecosystem, which provides habitat for other unique plants and animals. The invasive pine tortoise scale insect, *Toumeyella parvicornis* Cockerell, has been introduced to TCI, thought to be brought over from North America by the Christmas tree trade (Manco. B. N. *pers. comm.*), and is causing extensive damage to the Caribbean pine community (Figure 1.1). Across three pine forests of TCI, an estimated 90% of the pine trees have died due to the infestation (Martin Hamilton, *pers. comm.*). As the dominant species in the TCI pineyard habitat, the Caribbean pine has been identified as a conservation priority, by both the Government of TCI and the partners of the Caicos Pine Recovery Project (CPRP). Initial fieldwork undertaken by Royal Botanic Gardens Kew suggests that the entire *P. caribaea* var. *bahamensis* population on TCI is under threat from the invasive pest, with potentially high detrimental effects on the pineyard ecosystem (Martin Hamilton*, pers. comm.*).

Figure 1.1: Pineyard of Middle Caicos, after infestation of *Toumeyella parvicornis* (2011)

The pineyards of TCI are now facing a combination of threats, the largest being the invasive tortoise scale insect. The Caribbean pine and other plant species have developed a tolerance to the disturbance of hurricanes (O'Brien et al., 2008), a frequent occurrence in the Caribbean; however, the invasive scale insect lessens the resilience of the Caribbean pine making them more vulnerable to disturbance. Furthermore the pest has changed the dynamics of the pine communities' interaction with fire. The challenges of invasion and an increased susceptibility to fire and hurricanes add to the general threats of development and commercial use of Caribbean pine wood.

The extent and speed of impacts from the invasive scale insect, and other contributing threats, on the Caribbean pine means that the pineyards are in urgent need of protection and conservation.

1.2.1 Research

There is a concern that without effective management the Turks and Caicos Islands will find their national tree extirpated. Remaining pineyard habitats will subsequently be restricted to three islands in the Northern Bahamas and the southern tip of Florida, areas faced with the increasing threat of development. It is for this reason that research into the control of the invasive scale insect is necessary.

There has, as of yet, been little research into the invasive scale insect and no research into the effects of the Caribbean pine on the plant community in TCI. To be able to discern the consequences of the decline of the dominant pine and see the ecosystem changes which may occur this research is imperative. Further investigation is especially important when considering possible influences on other rare and endangered species, both plant and animal. As an already rare and declining habitat the loss of pineyards in the Turks and Caicos could have a significant impact on the islands' ecosystems and species diversity.

1.2.2 Policy

It is important to consider the wider implication of research in the development of national conservation strategies and on an international scale. The monitoring of the invasive scale insect and control methods efficacy will influence the approach taken to conserve the Caribbean pine *in-situ*. Population estimates will allow accurate conservation assessments including Red Listing of the Caribbean pine, which with increased research will hopefully draw more attention to the neglected but urgent need of the pineyard conservation, influencing national legislation and contributing to the international pine rockland research.

The work of the Caicos Pine Recovery Project (CPRP) contributes to the Global Strategy for Plant Conservation (BCGI 2011), a framework for plant conservation, under the international Convention on Biological Diversity (CBD). The monitoring and assessment of treatments for the control of the invasive scale insect directly influences Targets 2, 3, 7, 10, 14, and 16 (Botanic Gardens Conservation International 2011). Population estimates will provide the first steps towards developing an accurate conservation assessment of the Caribbean pine, after the invasive scale insect infestation, and in combination with monitoring will allow development of effective pine conservation protocols and management plans for the invasive scale insect which is threatening the pineyard plant community and ecosystem. The research undertaken will in the long-term contribute to *in-situ* species conservation through informing the development of Caribbean pine management plans. This work will also be communicated to the public through awareness efforts, comprising presentations and educational posters, through institutional partners in both the Turks and Caicos and the UK. Furthermore the research is undertaken with a number of partner organisations, the Department of Environment and Coastal Resources (DECR); Royal Botanic Gardens Kew (RBGK); Imperial College London, strengthening the international network for conservation of the Caribbean pine.

1.3 Aims and objectives.

This project will build on work undertaken by the CPRP and by Imperial College London MSc student Harry Earle-Mundi (2010), who established permanent monitoring plots for the Caribbean pine. The research is intended to contribute to the Turks and Caicos Islands long term management strategy for the Caribbean pine through investigation of the effects of current and proposed pine management strategies. The influence of the Caribbean pine on the surrounding plant community will also be investigated to determine the long-term impacts of pine declines within the ecosystem.

The aim of this research is to continue the monitoring of, and to develop a deeper understanding of the ecology of the Caribbean pine with the intention of informing and guiding management of the Turks and Caicos Islands pineyard habitats.

Objectives:

1) Investigate the effects of management strategies on the Caribbean pine

   a) Have the management strategies employed in the permanent monitoring plots (PMPs) controlled the invasive scale insect?
   b) What is the best management strategy for safeguarding the remaining pine trees in TCI?

2) Determine a population estimate

   a) Develop an accurate population estimate?
   b) What is the pineyard age structure?
   c) What proportions of the pines are dead?

3) Investigate the relationship between the Caribbean pine and the surrounding plant community

   a) What are the structure, composition and succession of plant spp. within pine yards?
   b) Is this different to non-pine and transitional areas?
   c) Does this change with a decline in the number of individual pines?
   d) What are the effects of pine decline on native flora?
   e) Does a decline in pines cause an increase in the native palm, *Sabal palmetto*?

2. Background

2.1 The Turks and Caicos Islands

The Turks and Caicos Islands (Figure 2.1), a UK Overseas Territory, is at the Southern tip of the Bahamian Archipelago and includes over 40 low-lying limestone islands covering an area of 430km^2 (Draper *et al.,* 1994). The country is characterised by a dry tropical climate with frequent summer hurricanes. The population of approximately 33,000 (2006 Census, Department of Economic Planning and Statistics 2011) is predominately located across nine permanently settled islands, with 1500, less than 300, and less than 100 residents on North Caicos, Middle Caicos and Pine Cay, respectively (see Figure 2.3).

Figure 2.1: The Caicos Bank (Google Maps, 2011)

2.2 *Pinus caribaea* var. *bahamensis*

The Caribbean pine, *Pinus caribaea* Morelet var. *bahamensis* (Griseb.) W.H. Barrett & Golfari, also known as the Caicos pine, is only found on three islands in the Turks and Caicos Islands: Pine Cay, North Caicos and Middle Caicos (Figure 2.2). Although the maximum recorded height observed in TCI is 8m (Earle-Mundil, 2010) the Caribbean pine can grow up to 30m tall.

Figure 2.2: *Pinus caribaea* var. *bahamensis*

2.2.1 Influence on Habitat

Pine forests of the Caribbean are thought to be an underappreciated area of biodiversity, receiving less attention than other forest types in research and conservation (O'Brien *et al.,* 2008). The pineyard ecosystem, is the most distinctive and threatened habitat in TCI (RBGK, 2011) and is internationally important as an endemic to the Bahamas archipelago. The Caribbean pine is the dominant species in the pineyard habitat and therefore a keystone species (Hamilton, 2010). Pine forests have high rates of endemism and support many rare and range-restricted species (Hamilton, 2010), for example they are a winter home for the endangered Kirtland's Warbler, *Dendroica kirtlandii*. Although only one of TCI's nine endemic plant species, *Stenandrium carolinae* Leonard & Proctor, has been found in the pineyards several plant species endemic to the Bahamas archipelago are present in the ecosystem (JNCC, 2010), such as *Tabebuia bahamensis* Britton., and *Thouinia discolour* Griseb., both of which are scarce and regionally restricted (JNCC, 2010). The existence of these endemic plant species within the pineyard habitat may provide additional impetus for the conservation of this declining ecosystem (Earle-Mundil, 2010).

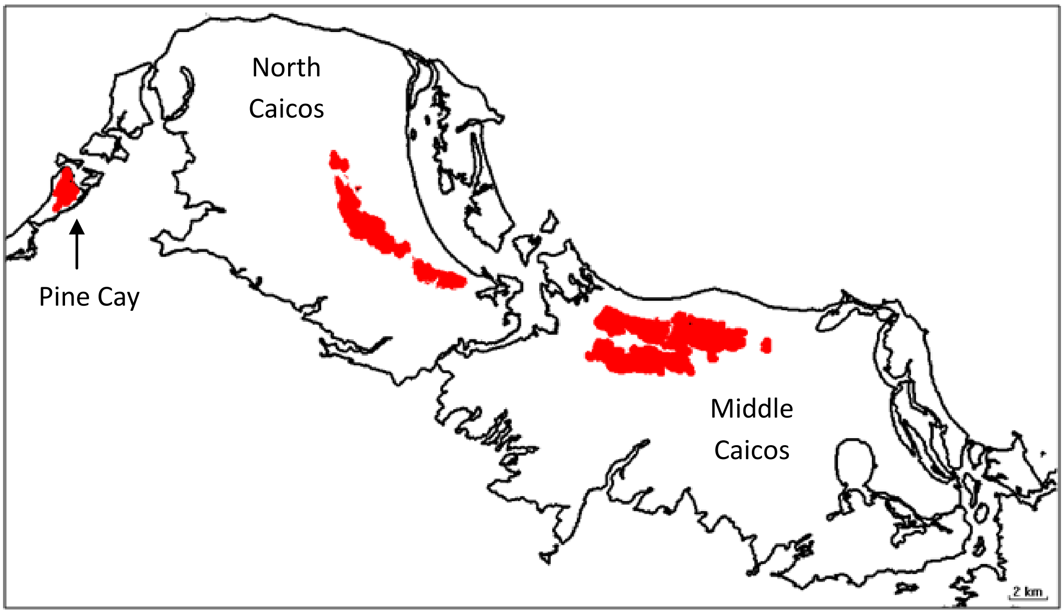

Figure 2.3: The mapped pineyards (red) of the Turks and Caicos Islands (UKOTs Team, RBGK, 2011)

2.3 Effects of Alien Invasive Species on Island Ecosystems

Island ecosystems are widely considered to be under threat from the impacts of invasive alien species (IAS) (Elton, 1958; Donlan *et al.,* 2003), the primary driver of ecosystem change and extinction on islands globally (Towns *et al.,* 2006; Clout and Veitch, 2002). Island ecosystems are particularly vulnerable to invasion (MacArthur and Wilson, 1967) and consequently IAS can have major consequences for species and ecosystem processes, leading to major alterations (Reaser *et al.,* 2007) and in extreme cases to the collapse of native ecosystems (O'Dowd *et al.,* 2003). Interacting influences on Caribbean islands, which are prone to natural disturbance, such as fires and hurricanes, and also increasing development pressure, are likely to exacerbate the effects of IAS (Mooney & Hobbs, 2002).

2.3.1 Pine Tortoise Scale Insect

The pine tortoise scale insect, *Toumeyella parvicornis* Cockerell (Figure 2.4) is responsible for the destruction of the pineyards in TCI. First discovered in Middle Caicos, in January 2005 by Martin Hamilton from RGBK (Hamilton, 2007; Hamilton *et al*., 2010), the invasive scale insect causes stunted growth, dieback, canopy death and reduced seed production of the Caribbean pine. In addition the invasive scale insect secretes honeydew which coats both the pine tree and the understorey layer, allowing the growth of sooty mould limiting photosynthetic capability.

In its native habitat of North America cold winters and predation restrict the spread and growth of the invasive scale insect. However, in the Caribbean warm temperatures allow the invasive scale insect to skip the hibernation phase of its lifecycle, reducing the time between generations and thus allowing an increased rate of spread.

Figure 2.4: *Toumeyella parvicornis* infected Caribbean pine

Since the initial infection, the invasive scale insect has spread to all areas of the pineyards across the three islands within TCI (Sanchez, 2008) and in combination with two severe hurricanes, resultant salinification and seasonal fires has drastically reduced the Caribbean pine populations. High mortality and low seed production continues across the islands providing support to estimates of extirpation from TCI within the following decade if conservation action is not undertaken (Caicos Pine Recovery Project Action Plan).

In 2010, the presence of the invasive scale insect, *Toumeyella parvicornis*, was confirmed on a Honduran pine *(Pinus caribaea* var. *hondurensis*) at a private residence and a plant nursery, in Puerto Rico (Segarra-Carmona and Cabrera-Asencio, 2010). It now appears this pest is moving through the Caribbean. The origin of introduction is not known, but like TCI it is thought the pest was carried in on a Scots pine from North America, imported in the Christmas tree trade. Unlike TCI Puerto Rico has no native pine species, so the impact of the invasive scale insect is likely to be restricted to reforestation projects, the main use of the Caribbean pine in Puerto Rico.

2.4 A Fire Dependent Ecosystem

Naturally a fire dependent ecosystem, periodic burning is necessary to maintain pine succession and regeneration. Regular burning maintains the pineyard habitat and prevents the tropical broadleaf understorey, including species such as *Lysiloma latsiliquum* and *Swietenia mahogani*, and palms including *Sabal palmetto* and *Thrinax morrissi*, outcompeting the pine overstorey. Without fire the pines will eventually disappear, with canopy closure taking around 30 years (Myers, Wade and

Bergh, 2004). The loss of a pineyard with multiple age- classes and open canopy gaps will not allow the persistence of highly diverse herb and low density shrub layers (Pine Rockland Working Group, 2010). Conversely, too frequent fires, less than every 3 years, renders seedlings vulnerable, not developing in maturity enough to escape fire mortality (Miller, 2007; O'Brien *et al*., 2008). The ideal frequency of burning is occurring 3 – 7 years (Synder *et al*., 1990).

The invasive scale insect not only increases pine mortality directly but disrupts the fire regime, increasing pine susceptibility to fire, and eliminating pine regeneration (Hamilton, 2010). Through increasing the stress level of the pines the invasive scale insect exacerbates the vulnerability of mature pines to fire, consequently increasing mortality and decreasing long-term seed production. Furthermore, it prevents many seedlings from reaching maturity, reducing recruitment numbers and succession.

2.5 Fire use in TCI

The traditional agricultural technique in TCI includes periodic burning of the land and as a mean to dispose of cleared vegetation. Anthropogenic fires, such as these, can and have spread to the pineyard causing dire consequences. In 2009 the Ready Money pineyard, the Southern extent in North Caicos, was ignited accidentally resulting in mass tree mortality with next to no seedling regeneration (Hamilton *et al.,* 2010). Conch Bar pineyard, in Middle Caicos, was burnt in similar circumstances less than a decade ago. In combination with the invasive scale insect the mortality of mature pines almost reach 100%, however mass seedling regeneration did occur but the majority of these are now infected with the invasive scale insect. Severe damage will be caused if an unplanned fire reaches the pineyards (Field Visit Report, 2010), particularly on Middle Caicos, and it is therefore paramount to work with local communities to ensure a burning event like that of 2009 is adverted in the future.

2.6 Legislation and Conservation

Since the discovery of the invasive scale insect in TCI conservation work has been undertaken in collaboration between the TC National Trust and RBGK. As a conservation issue, the plight of the Caribbean pine is relatively recent, with conservation efforts starting in 2007.

The IUCN Red List of Threatened Species, only lists the species, *Pinus caribaea*, and does not go down to the variety *bahamensis* (IUCN, 2011). The species is listed as Least Concern. However having been listed in 1998, before the infection of the Turks and Caicos pineyards, this needs to be updated. What this does not take into account is the rare habitat of the pine rocklands which this species variety creates in TCI, the Bahamas and Southern Florida. Adding the habitat consideration into the data clearly demonstrates the listing as least concern is an underestimate of the threatened status of the Caribbean pine.

As of yet there is no legal protection of plants species within TCI, except within National Parks (JNCC, 2011). The infestation has raised the awareness of imported plant pests in TCI, resulting in the Endangered Species Act to include prohibition of importing untreated pine, and palm, material into the country (Manco. B. N. *pers. comm.*). The Environmental Health Department is now doing more to prevent further plant pest introductions by increasing plant inspections (Manco. B. N. *pers. comm.*). Under final review is The Endangered Species Bill, which includes provisions for the Convention on International Trade in Endangered Species (CITES), which when ratified will protect the pine and the pineyard habitat from destruction (DECR, 2008; Manco. B. N. *pers. comm*). In TCI, lack of law enforcement is a major problem for species legislation (JNCC, 2011).

The Turks and Caicos Islands are included under the UK's ratification of international agreements including the Convention on Biological Diversity (CBD) and CITES. The CBD has repeatedly called on member countries to focus on the conservation of evolutionary and geographically isolated ecosystems, such as islands (CBD, 2011), due to the vulnerability of island ecosystems to the impacts of IAS. One notable part is Article 8(h) of the Convention on Biological Diversity which calls on Parties to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats, or species". Consequently, it is the responsibility of the TCI government, to not only develop strategies for the eradication of the invasive scale insect, but to also reform legislation to prevent similar introduction from occurring in the future. Increasing phytosanitary regulations and monitoring needs to be treated as a priority in TCI.

2.6.1 Global Strategy for Plant Conservation

In response to the continuing loss of plant biodiversity the Global Strategy for Plant Conservation (GSPC) was developed. The GSPC aims to ensure the conservation of plants and the ecosystem services they provide, by halting the current and continuing loss of plant diversity (Botanical Garden Conservation International, 2011). Adopted in 2002, by the Conference of Parties (COP) 6, it is the first target-driven strategy to be developed under the CBD and includes 16 outcome-oriented global targets which were to be achieved before 2010 (RBGK, 2011). The targets are set within five broader objectives:

Objective 1: Understanding and documenting plant diversity (Target 1 - 3)

Objective 2: Conserving plant diversity (Targets 4 - 10)

Objective 3: Using plant diversity sustainably (Targets 11 - 13)

Objective 4: Promoting education and awareness about plant diversity (Target 14)

Objective 5: Building capacity for the conservation of plant diversity (Target 15 - 16)

These sixteen targets provide a framework for which member countries can implement the GSPC. Current conservation work on the Caribbean pine, by the CPRP and associates, contributed to the achievements of six of the sixteen targets:

The UKOTs Programme, RBGK, is working with partners in all Territories to implement the GSPC (UKOTs Online Herbarium, 2010). Progress has been made in implementing the targets within the Turks and Caicos Islands (RBGK: Turks and Caicos Islands, 2011). Not all targets correspond to the conservation of the Caribbean pine, but are focused on the national plant biodiversity.

The GSPC has been a good guideline for the implementation of international strategies relating to plant conservation, especially in the regions of capacity building and education (UKOTs Online Herbarium, 2010; Torres-Santana *et al.,* 2010). Objectives 2 and 3 could use more focus and attention, as key to achievable plant conservation, but largely the implementation of strategies is good across the targets (Table. 2.1). With the support and guidance of RBGK, the Turks and Caicos Islands can achieve a wider set of targets, not just in relation to the Caribbean pine, but to all national plant life.

2.6.2 Past Work

Past work concerning the Caribbean pine is largely directed towards fire management, with research primarily focused in the Bahamian pineyards, which compromises a different habitat and climate from the pineyards in TCI (Manco. B. N. *pers. comm.*). Within TCI little research has been done in the pineyard let alone research into management before the invasion of the scale insect (Manco. B. N. *pers. comm.*). An example of research into fire management in the Bahamas is the MSc thesis of Alison Miller (2007), “Fire History of Caribbean pine (*Pinus caribaea* var. *bahamensis* (Griseb.) W.H. Barrett & Golfari) Forests on Abaco Island, the Bahamas”. The aim of her research was to aid the forest manager in their understanding of the dynamics of fire in the Bahamian pineyards, with the intension of establishing a greater understanding of fire regimes allowing management agencies to design a better fire management plan. Fire ecology and management is a necessary part of Caribbean pine conservation. In 2003, The Nature Conservancy and associated experts in the field made recommendations for the conservation of the Bahamian pineyards which addressed fire management and public education of the role and importance of fire in the pineyard ecosystem (The Nature Conservancy, 2003; Miller, 2007).

Additional work undertaken by RBGK is the chemical analysis of pines. Preliminary data, collected by Martin Hamilton and Michele Sanchez in the Bahamas and TCI and analysed by Mark Cox as part of the Kew Horticulture Diploma, indicated that there were qualitative chemical differences between extracts of healthy and insect-infested pine (Field Visit Report, RBGK, 2011). Paul Green (Jodrell Laboratory, RBGK) analysed additional samples and confirmed these findings. The work undertaken by Kew on the chemical analysis of the pines is only preliminary and needs to be expanded for any meaningful results to be gained or knowledge to be gained.

In collaboration between Birkbeck University London and RBGK, as an aspect of her PhD research project, Michele Sanchez is researching into the morphological and genetic characteristics of the Caribbean pine across its distribution range (Sanchez, 2010). The results of her research will provide information on the genetic and ecological factors influencing the Caribbean pine populations and the pineyard habitat, and may provide a key insight into biological mechanisms which must be included in effective long-term conservation management of the Caribbean pine.

2.6.3 Caicos Pine Recovery Project, DECR

The Caicos Pine Recovery Project are working to protect the Caribbean pine and the pineyard ecosystem from, *Toumeyella parvicornis*, and to ensure its recovery to maintain ecological integrity as a fire dependent community. A pilot project for the recovery of the Caribbean pine was initiated in 2008, by the Turks & Caicos National Trust (TCNT) in collaboration with project partners the Royal Botanic Gardens Kew (RBGK), Environmental Health Department, and the Department of Environment & Coastal Resources (DECR). The main outcomes of this project were the establishment of a pine nursery, which focused on the collection and cultivation of wild seeds founding an *ex-situ* collection, and mapping the pineyard ecosystem and the extent of the invasive scale insect infection (DECR, 2010). Furthermore, the Caicos Pine Recovery Project working group, including international partnerships with the Royal Botanic Gardens, Kew; Bahamas National Trust; Bahamas Department of Agriculture; The Nature Conservancy; and the US Forest Service, were formed. In December 2009, due to a takeover in governance by the UK, and funding collapse, the DECR took occupation of the pine conservation nursery and became the lead collaborator of the project (DECR, 2010).

The long-term aim of the Pine Recovery Project is to ensure the survival of the Caribbean pine, with the goal of having healthy pest-free populations of pine established on each island as well as an *ex-situ* collection, as outlined in the action plan (DECR, 2010). The intention is that the CPRP will continue until the Caribbean pine has made a full recovery (Earle-Mundil, 2010); the action plan has a timeline of ten years. Priority activities for the future are to propagate individual pines immune to the invasive scale insect, assessment of pineyards for fire management trials, systematic insecticide application, and continuation of awareness campaigns, capacity building and networking (Salamanca, 2010). RBGK has role to undertake field research, amongst others (RBGK, 2011), such as the MSc thesis of Harry Earle-Mundil, which was to establish pine monitoring plots.

2.7 Permanent Monitoring Plots

In 2010 Harry Earle-Mundil of Imperial College London, in partnership with RBGK, undertook his MSc thesis with the Caicos Pine Recovery Project. The main objectives/outcomes of the project were to establish permanent monitoring plots (PMPs) and to develop understanding of morphological and ecological data which may be useful in guiding the management of the Turks and Caicos pineyard habitat. This monitoring will be used to record the spread of the invasive scale insect and the consequential change in pine habitat, in the hopes of discovering areas suitable for replanting a healthy *ex-situ* population.

The randomised block design of the PMPs, allowing the analysis of different treatments, was based on guidelines outlines in Alder and Synott (1992), which advises a simplified approach to the design of the experimental plots. They emphasise the need for correct statistical design allowing meaningful conclusions to be drawn. Plots were established across the three islands containing pineyards, one for each of three treatment types, with one of these being a control.

The 20 x 20m plots were established on each island, one to receive each of the three prescribed treatments (Table 2.1), which have since been carried out in the last year by the CPRP, who maintain the plots. The plots size was selected as manageable and attainable, able to fit into available crown land, and were selected through random point generation but limited to accessible areas within the pine yards and which had enough pine trees suitable for the experiment (Manco. B. N. *pers. comm.*). Baseline data to allow future monitoring, was collected of all the ecological and environmental variables within the plots (for details see Methods), including a full species list.

Treatment	Description (Earle-Mundil, 2010)	Plots treated	Implementation
Vegetation Control	Vegetation will be cleared to a distance of 1.5m around each pine tree in the plot on a bi-annual basis.	3, 6, 9	Broadleaf control carried out "as needed", or twice a year, with minor work after the rainy season.
Vegetation Control and Soap Spray	Vegetation will be cleared to a distance of 1.5m around each pine tree in the plot on a bi-annual basis. Soap spray will be applied to each pine tree in the plot on a quarterly basis	1, 4, 7	Broadleaf control as above; Soap spray application once within the last year, but to be continued every six months.
Control	No management action will be undertaken	2, 5, 8	N/A

Table 2.1: Treatments of the nine Permanent Monitoring Plots (Earle-Mundil, 2010; Manco. B. N. p*ers. comm.)*

2.7.1 Islands

As part of his thesis Earle-Mundil compared the PMPs with one another and between the pineyards, using a Single Factor Analyses of Variance (Earle-Mundil, 2010). His statistics demonstrated a significant difference in size and maturity between pine trees from Middle Caicos and Pine Cay, as well as difference between the canopy height and scale infestation level between these two islands. The reason for the mature community in Pine Cay in comparison to Middle Caicos is thought to be due to there having been no recent fire on Pine Cay. In Middle Caicos, due to the recent burn and a higher level of infection, there has been almost total mortality of mature trees, leaving the majority of the population as seedlings. The majority of pines being saplings on North Caicos indicate a mid-stage of succession, due to burning within the last decade; however this means North Caicos has a much denser understory than Middle Caicos. Without the presence of a seed source, due to lack of mature trees, this has large implications as fire will not encourage pineyard regeneration but hasten the conversion of the pineyard to a broadleaf community (Pine Rockland Working Group, 2010).

2.7.2 **Trees and Plots**

Regarding the difference in individual trees within the plots on each island, no significant difference was found, suggesting the condition of the pines and intensity of infection is similar between pineyards. Between individual PMPs within pineyards significant difference was found in scale infestation in North and Middle Caicos, but no difference at Pine Cay. Earle-Mundil therefore made the recommendation that efficacy of treatments should be measured as change from the original state of individual plots and not as a mean baseline, to ensure effective comparison and adequate monitoring. Significant difference in the level of sooty mould was also found between plots on Middle Caicos. Furthermore nearly all variables were significantly different between PMPs and other CPRP data, however this data is not directly comparable as temporal differences in data collection took place.

2.7.3 **Plant Community**

Species which were highlighted as common within the PMPs, and therefore deemed as characteristic pineyard vegetation, were *Tabebuia bahamensis*, *Rhynchospora floridensis*, *Angadenia berteroi*, *Ernodea serratifolia*, *Leucothrinax morrisii*, *Erithalis fruticosa* and *Coccoloba uvifera*. It was found by Earle-Mundil that Middle Caicos pineyard was the most species rich, most likely because it is the pineyard which has most recently burned and is therefore in the early stages of fire-climax succession, characterised by an open canopy, a high diversity of herbaceous species, as well as a high regeneration of pines (US Fish and Wildlife, 2011).

2.7.4 Critique

The PMPs established in 2010 will be a useful tool for determining successful treatments for the control of the invasive scale insect and for the monitoring of the Caribbean pine. It is the first step of the CPRPs pine monitoring, to enhance development of effective conservation strategies. The data recorded encompasses a large variety of ecological variables, suitable for measuring the spread of the invasive scale insect and level of infection, however there is only a small number of environmental variables recorded. These would be useful to determine if environmental stresses increase the susceptibility of pines for infection, for example, the level of flooding and consequential salinity. To be able to look at this, especially in association with control treatments, a larger plot size would be needed. Although the sample size is adequate to be able to draw significant results, if this size was to be increased the statistical power would be greater and the results would be more meaningful. However this may not be possible due to problems initially incurred when establishing these original nine plots, such as random point generation selection of crown land with a suitable number of trees within the plot. As it is it may be that the monitoring plots are fine as they are and any additional experiments can be done by other methods in a wider area through the pineyard. However, considering the efficacy of treatments, to be able to see variance between pineyard in different succession stages replicate plots within each pineyard would be needed. Assessing the difference of treatments for pineyards in different succession changes could have useful management implications.

The treatments carried out by the CPRP were applied within a 2 week time span across the three islands (Table 2.2). All were carried out at roughly 11 am in partly cloudy conditions after light rain. The Soap Spray application and broadleaf control were carried out as close together in time as possible reducing the influence of any temporal variation. Furthermore the islands do not seem to have been subject to any varying conditions, such as fire, since the plots were established.

Island	Plots treated	Date of treatment	Amount of SaferSoap spray used in Vegetation control and Soap Spray Plot (2.5 fl oz per US gallon of rain water)
North Caicos	4, 5, 6	24th February 2011	1 mixed US gallon
Middle Caicos	1, 2, 3	23rd February 2011	2 mixed US gallons
Pine Cay	7, 8, 9	9th March 2011	1.5 mixed US gallons

Table 2.2: Practical treatment details (Manco. B. N. *pers. comm*.)

The PMPs were shown to be significantly different from the pineyards as a whole, although limitation in the data may be responsible for some bias. If unrepresentative, the plots should be treated as a separate entity and should not be compared with the pineyard as a whole. Direct comparisons of the PMPs year on year can only be used in analysis unless the methods and data collection protocols are comparable.

2.7.5 Consideration for Continued Monitoring

It is important when analysing data from two successive years that they are comparable, therefore the same data collection methods must be used in all successive monitoring. For data collection standards see Methods. Additionally it is a good idea to monitor in the same time of year so that there is no influence of seasonal variation of data variables.

Considering the differences which have been shown in the succession and tree heights between the islands, analysis must be comparative between years, using baseline data and newly collected data, in contrast to using data from one year.

Although not directly relevant to the monitoring and conservation of the Caribbean pine it is important to continue the monitoring of the species richness within the plots, to detect any changes correlated with the application of treatments. It is important to consider the effects the treatments can have on the native vegetation, for example broadleaf clearance around pine trees could cause some species to be lost from within the plots. Consideration of which species are to be cleared is prudent as it might be necessary to leave some plant species unharmed during clearance if they are more vulnerable, such as those plants which are slow growing, for example oligotrophs, *Pilosocereus royenii*, *Tillandsia* spp. and *Encyclia* spp. (Earle-Mundil, 2010).

3. Methods

3.1 Monitoring of Permanent Pine Plots

To determine the effects of the management strategies used by the DECR to control the invasive scale insect and to answer the question of which is the best strategy for safeguarding the remaining pine trees in TCI, it is necessary to monitor the pine plots created by the Earle-Mundil (Earle-Mundil, 2010), the DECR and Kew. Through the assessment of the relative treatments, outlined above, it will be possible to determine the impacts and conclude if any treatment is an effective strategy the DECR can use to control of the invasive scale insect. Monitoring the health of the pine trees and identifying an effective management strategy is necessary to guide the management and conservation of the Turks and Caicos Island pineyard habitat.

The effective monitoring of the PMP's relies on the consistency of data collection, therefore all data collected corresponds to the standards outlined and used by Earle-Mundil (2010) in the collection of the baseline plot data (Table. 3.1) and individual tree data (Table. 3.2). Appendix 1 contains a full description of all data collection standards.

Variable	Description
Height of Canopy	The average height of vegetation in the PMP in metres. Estimated by eye to the nearest 5%.
Canopy Density	The percentage canopy cover of vegetation in the PMP. Estimated by eye to the nearest 5%.
Ground Cover	The percentage of ground covered by vegetation. Estimated by eye to the nearest 5%.
Level of Pine Tortoise Scale Infection	The average level of scale infection in the PMP. Measured on a scale of 0 – 5; 0 being scale free; 5 being scale covering every pine tree in the PMP.
Level of Canopy Damage	The average level of pine tree canopy loss in the PMP. Measured on a scale of 0 – 5; 0 being no canopy loss; 5 being total canopy loss in the PMP. Dead trees were included in the assessment.
Sooty Mould Coverage	The coverage of sooty mould, recorded as a percentage of the total leaf area covered by mould. Estimated by eye to the nearest 5%.
Height of the Tallest Tree	The height of the tallest pine tree in the plot in metres.
DBH of the Tallest Tree	The diameter at breast height (1.27m) of the tallest pine tree in the plot in centimetres.

Table 3.1: Data Collection Standards for PMP's (Earle-Mundil, 2010)

Variable	Description
Level of Pine Tortoise Scale Infection	The level of scale infection on the tree. Measured on a scale of 0 – 5; 0 being scale free; 5 being totally infested.
Level of Canopy Damage	The level of canopy loss to the tree. Measured on a scale of 0 – 5; 0 being no canopy loss; 5 being total canopy loss.
Sooty Mould Coverage	The coverage of sooty mould, recorded as a percentage of the total leaf area covered by mould. Estimated by eye to the nearest 5%.
Tree Height	The height of the tree in metres.
Tree DBH	The diameter at breast height (1.27m) of the tree in centimetres. For saplings and seedlings that did not reach 1.27m, the diameter 4cm from the base of the tree was measured instead.

Table 3.2: Data Collection Standards for Individual Trees (Earle-Mundil, 2010)

Measurements of Tree Height, which could not be measured by hand, were determined using a clinometer and all DBH field measurement were taken using a DBH tape. In the field data were recorded directly into ArcPad (ESRI Version 7.0) using a handheld PDA with integrated GPS. The projection used was WGS_1984_UTM_Zone_19N. Recorded data were managed within BRAHMS (Botanical Records and Herbarium 16 Management System, available to download from Oxford University http://dps.plants.ox.ac.uk/bol/). In addition to the pine tree data, for each PMP a full species list was compiled with the assistance of B. N. Manco of the DECR.

Analysis

Data collected were compared to the baseline data collected by Earle-Mundil (2010). All analysis was done using R (CRAN). A mixed-effects model was used to analyse the data using R package lme4 (Bates *et al*., 2011), with island as a random effect. Both seedlings and mature trees are found within the plots, with the varying growth rate taken into account by multiplying the height and DBH by the mean of each tree of both years of monitoring.

3.2 Pine Density and Decline

It is important to have an accurate population estimate of the Caribbean pine within the Turks and Caicos Islands, and to have estimates of decline, to allow adequate species assessment and effective management. Without an idea of the population size and the number of pines which have been killed, we cannot gain an understanding of the true effect the invasive scale insect is having on the Caribbean pine population. Furthermore the extent of the pine mortality could differ from that estimated, which could potentially have wide consequences for conservation strategies and for funding applications.

To be able to establish the total decline of Caribbean pine trees due to the combination of the invasive scale insect and fire, it is necessary to determine the density of pine trees throughout the pineyards and the ratios of live and dead pine trees. All three pineyards (see Appendix 2) will have a discrete density value as all vary due to ecosystem isolation and ecological and environmental variance. Further to noting the living status of the pine trees, the live trees are separated into the categories mature and immature, determined by the presence of cones. Additionally the age of cones is recorded to determine current reproductive status. Through calculating the density and number of pines which are mature it may provide a more realistic estimate of pine survivorship, as in the case of a pineyard fire the younger pines which have not yet reached reproduction age will most likely die. Therefore an estimate of total pine density may be misleading as to the current state of the pineyard habitat.

Establishing pine density is achieved through transects on each island within the pre-defined pineyard boundary as mapped by CPRP and RBGK (Hamilton *et al.*, 2010). On each island ten transects, of a North-South orientation, contain five plots of 10x10 metres. It is attempted to achieve the largest variation in area throughout the pineyard to reduce the likelihood of establishing a biased pine density. Achievement of this is largely dependent on accessibility and time allowances, for example Pine Cay, which has a pineyard of 1.07 km^2 and is heavily dissected with roads, is suitable for achieving a wide spread of transects, in contrast to the pineyard of North Caicos which is largely inaccessible being surrounded with dense dry tropical broadleaf forest.

Where able random points were generated in arcMAP 9.3 within the outlined pineyards; areas which were not accessible are excluded and points shifted to allow a full N- S transect within the pine yard boundary. Random point generation is not possible on North Caicos due to the majority of the pineyard area being largely inaccessible, so the largest spread of transects were created in areas which accessibility allowed.

The criteria for calculating the number of dead and live pine, is the presence of the tree stump within the 10x10m plot. Surveying took place in the wet season and so large areas were flooded, particularly in Ready Money, the southern section of the North Caicos pineyard and throughout the pineyard in Middle Caicos. It is likely that high levels of flooding will reduce the detection probability of dead and fallen pines, underestimating the numbers of dead pines recorded. In addition further data was collected, relating to the invasive scale insect (see PMP data collection standards above), which may be useful to CPRP for monitoring the spread and for future analyses.

Analysis

Extrapolation of the population estimates has been done using the mean stand density, from taking the mean pine density of all 50 plots on each island. Mean pine density per island was extrapolated to the islands total area of the mapped pineyard, determined from arcMAP 9.3. Extrapolation was done for mature pines, immature pines, live pines, dead pines, and total number of pines, incorporating both live and dead (Appendix 3).

3.3 Influence of the Caribbean Pine on the Surrounding Plant Community

The decline of the Caribbean pine is likely to be having wider effects throughout the pineyard habitat. As Caribbean pine is the dominant species, it is important to investigate the influence that the invasive scale insect will have on the habitat as a whole. To enable the ecosystem and community impacts it is necessary to determine the species composition within the pineyard. Not only can a pineyard species index be valuable for future monitoring of compositional change associated with a decline in pine number but can be used to determine the influence of pine density of individual species.

The density transects within the pineyards therefore also include a species assessment. Middle Caicos transects contain a complete species list, whereas North Caicos and Pine Cay only the presence of palms are recorded, *Sabal palmetto* and *Thrinax mosirrii*, as time and accessibility were a limiting factor. The species composition varies slightly between the pineyards situated on the three islands. North Caicos, and to a lesser extent Pine Cay, appears to have a higher abundance of palm species associated with the decline of the Caribbean pine.

Pine density data and species composition data can be used to investigate the influence that the declining number of pines have on the surrounding flora, and thus provide some insight as to how the pineyard habitat may change. This is relevant for the conservation of rare pineyard associated species, such as *Heterosavia bahamensis* and *Angadenia berteroi*. Within the pineyard boundary there are pockets of non-pineyard habitats and transitional habitats between pineyard and tropical dry forest, allowing sampling of a range of pine densities including areas absent of Caribbean pine.

Analysis

Analysis of species data was comprised of a mixed-effects model, using R package lme4 (Bates *et al*., 2011), with a Poisson error distribution, and an ordination, using the R statistical package VEGAN (Oksanen *et al.*, 2010). An ordination was done to investigate the possible effects of pine trees on species richness and species abundance determined by clustering of similar plots. For the ordination all pine density data was included; Mature Pines, Immature Pines, Live Pines, Dead Pines and Total Pines; for each variable 100 iterations were run. Although the species data was only collected on Middle Caicos, the data collected for palm abundance, *Sabal palmetto* and *Leucothrinax morrisii*, was collected across all three islands, therefore, “island” was included as a random effect within the mixed effects model. For all species “transect” was include as a random effect. Significance of variables was assessed by removing them from the model and testing between the models with Chi square.

4. Results

4.1 Monitoring of Permanent Pine Plots

4.1.1 Plots

The results of second year monitoring of the PMP plot data are presented in Table 4.1, which shows the difference between years and between treatments, and the interaction between both, for a number of ecological variables measured. The majority of variables, including level of sooty mould, DBH of tallest tree, height of tallest tree and plot species richness, had no significance for any of the tests. The ANOVA showed a significant decrease in the mean canopy loss between years for all treatment types (d.f = 1; $p < 0.01$), but no significance between different treatments. Figure 4.1, shows the change in the mean of treatments between the two years for each recorded variable. A significant difference is seen between years (d.f = 1; $p < 0.05$), treatment (d.f = 2; $p < 0.05$) and the interaction between them (d.f = 2; $p < 0.01$), of the level of scale infestation. The level of scale infestation remains constant for both broadleaf clearance & soap spray and the control treatment. However, the broadleaf clearance causes a significant increase in the mean scale infestation. It is likely that if both treatment and year are significantly different that there will be a significant interaction between the two variables.

Table 4.1: Presents the results of an ANOVA showing the significance of Treatment types within the CPRP permanent monitoring plots, from 2010 to 2011, for a number of environmental variables.

Variable	Interaction	d.f.	F value	Pr (>F)	Significance
Level of Scale Infestation	Treatment	2	6.6667	0.014458	<0.05
	Year	1	8.8889	0.013774	<0.05
	Treatment: Year	2	8.8889	0.006047	<0.01
Canopy Loss	Treatment	2	0.3271	0.728441	NS
	Year	1	11.9626	0.006136	<0.01
	Treatment: Year	2	0.3271	0.728441	NS
Level of Sooty Mould	Treatment	2	0.1264	0.88262	NS
	Year	1	4.7145	0.05505	NS
	Treatment: Year	2	1.4233	0.28579	NS
DBH of Tallest Tree	Treatment	2	0.2271	0.80086	NS
	Year	1	3.5848	0.08757	NS
	Treatment: Year	2	0.3281	0.72775	NS
Height of Tallest Tree	Treatment	2	0.3028	0.74528	NS
	Year	1	3.7719	0.08079	NS
	Treatment: Year	2	0.5612	0.5875	NS
Plot Species Richness	Treatment	2	0.7943	0.4784	NS
	Year	1	0.4597	0.5131	NS
	Treatment: Year	2	0.0762	0.9272	NS

Although not significant, it is interesting to note from Figure 4.1 that the mean level of sooty mould decreases ever so slightly for broadleaf clearance & soap spray, but increases for the other two treatments. From the level of scale of infestation, canopy loss and level of sooty mould, it could be argued that the broadleaf clearance & soap spray treatment demonstrates the best results from the year of monitoring. The treatments and time seem to have little effect on the mean height, DBH and species richness within the PMP plot data. Both the height and DBH of the tallest tree within PMPs show a decrease in the last year. Considering that the same individual trees were measured in both years, with no tree mortality, this may highlight a lack of continuity within the data collection methods. The mean species richness within monitored PMPs shows a small non significant increase for all treatment types, with broadleaf clearance showing the smallest rise.

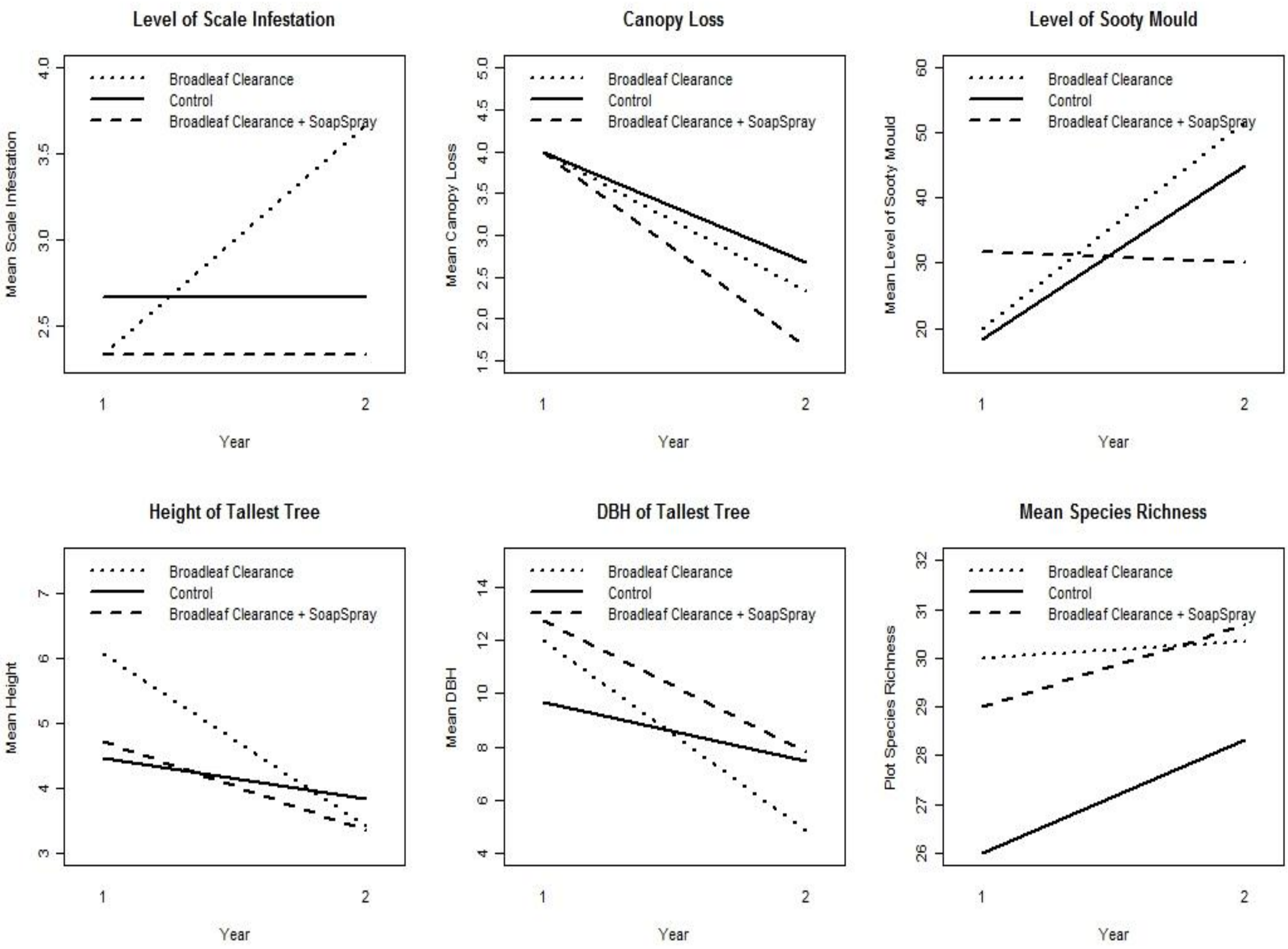

Figure 4.1: Plots of environmental variables illustrating change in means, relative for three CPRP plot treatments, from 2010 to 2011.

4.1.2 Trees

The data of individual trees within the PMPs shows a greater level of significance for the variables recorded (Table 4.2). Level of scale infestation, canopy loss and level of sooty mould all showed a significant difference between years (d.f = 1; $p < 0.001$), treatment types (d.f = 2; $p < 0.001$) and an interaction between the two (d.f = 2; $p < 0.001$). From the environmental variables collected from individual trees, represented in Figure 4.2, it is possible to see the significant differences in treatment and year. The level of scale infection has significantly increased in a year (d.f = 1; $p < 0.001$) with the largest increase seen in the treatment broadleaf control, with similar increases between the other two treatments. The mean canopy loss has significantly decreased within the last year, and as with infestation level, has a significant disparity between treatments (d.f = 1; $p < 0.001$), with the largest reduction in mean canopy loss being the control plots, seconded by broadleaf clearance & soap spray application. Surprisingly, the level of sooty mould significantly increased vastly between years. A significant difference between treatments (d.f = 2; $p < 0.001$) shows the largest rise was in plots subjected to broadleaf control, with the other two treatments showing a similar increase.

Table 4.2: Presents the results of an ANOVA showing the significance of Treatment types of individual trees within the CPRP permanent monitoring plots, from 2010 to 2011, for a number of environmental variables.

Variable	Interaction	d.f.	F value	Pr (>F)	Significance
Level of Scale Infestation	Treatment	2	18.379	1.59E-08	<0.001
	Year	1	271.606	2.20E-16	<0.001
	Treatment: Year	2	10.419	3.43E-05	<0.001
Canopy Loss	Treatment	2	12.8397	3.27E-06	<0.001
	Year	1	78.5293	2.20E-16	<0.001
	Treatment: Year	2	8.3978	0.000247	<0.001
Level of Sooty Mould	Treatment	2	13.859	1.22E-06	<0.001
	Year	1	273.751	2.20E-16	<0.001
	Treatment: Year	2	11.272	1.50E-05	<0.001
Mean DBH of Trees	Treatment	2	0.8431	0.430781	NS
	Year	1	11.3442	0.000794	<0.001
	Treatment: Year	2	0.3443	0.708821	NS
Mean Height of Trees	Treatment	2	1.287	0.27667	NS
	Year	1	6.1644	0.01324	<0.05
	Treatment: Year	2	0.1501	0.86061	NS
Tree Mortality	Treatment	2	3.2349	0.03988	<0.05
	Year	1	23.5931	1.43E-06	<0.001
	Treatment: Year	2	2.3631	0.09478	NS

A significant difference was found between years in the mean height (d.f = 1; $p < 0.05$) and DBH (d.f = 1; $p < 0.001$) of the trees. Tree mortality has a significant difference between years (d.f = 1; $p < 0.001$) as well as treatment type (d.f = 2; $p < 0.05$), but no significant interaction between them. Although a significant difference between years was demonstrated by the results of the ANOVA, neither of the mean DBH or mean height (Figure 4.2) seem to show a large difference between years or treatments. The mean mortality of trees shows a significant increase (d.f = 1; $p < 0.001$),which is unsurprising when comparing collected data to baseline data. Of the significant difference in the effect of treatments, the highest mortality was found in broadleaf clearance plots, and the lowest in the control plots (d.f = 1; $p < 0.05$).

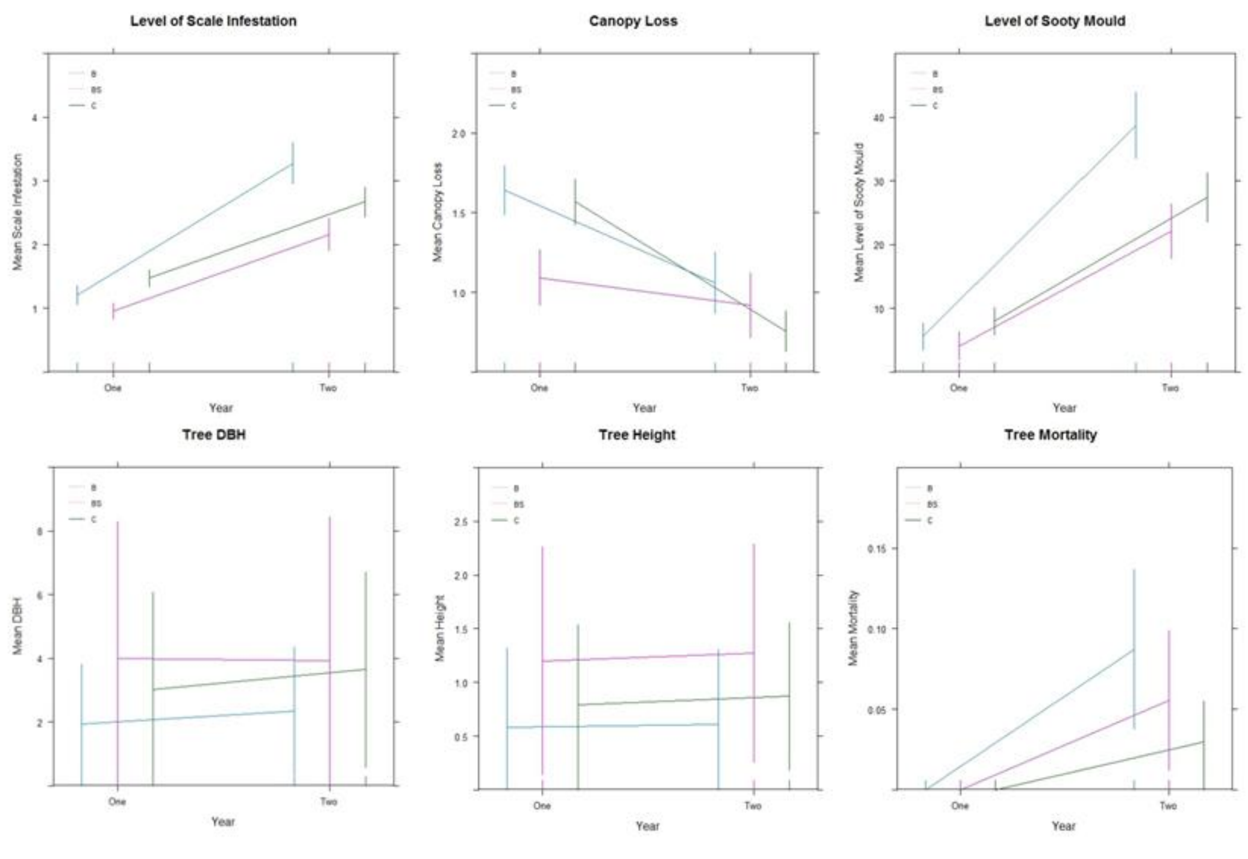

Figure 4.2: Plots of environmental variables illustrating change in means, relative for three CPRP plot treatments, of individual trees, from 2010 to 2011.

4.2 Pine Density and Decline

Population estimates of the Caribbean pine for each island have been calculated and have been summarised in Table 4.3 (for full details see Appendix 3). The total population estimate of live trees for all three islands is 734,893, with 1.45 % of these being mature trees and 98.55% being immature. There is an estimated 57.48 % decline of pines with 993,320 dead pines estimated across the three islands. From these estimates it can be deduced that 97.55 % of mature trees have been killed by the impacts of the invasive scale insect and pineyard fires, in combination with natural mortality rates.

Population Estimate	North Caicos		Middle Caicos		Pine Cay		Total	
	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
Mature Pine	0	0	24,329.4	11,093.5	652.6	368.9	24,982.0	11,099.6
Immature Pine	14,295.9	7,102.8	643,622.5	154,770.9	51,992.7	11,084.5	709,911.1	155,329.8
Live Pine	14,295.9	7,102.8	667,951.9	159,993.1	52,645.3	11,140.1	734,893.1	160,537.7
Dead Pine	205,860.8	35,352.2	765,269.4	86,027.6	22,189.4	3,528.2	993,319.5	93,075.1
Total Pine	220,156.7	36,235.1	1,433,221	210,609.1	74,834.7	12,144.6	1,728,212.6	214,048.2
% Decline (of total)	93.5	22.2	53.4	9.9	29.7	6.7	57.5	8.9
% decline (of mature)	100	24.3	96.9	15.2	97.1	21.6	97.6	12.8
% Mature (of total)	0	0	1.7	0.8	0.9	0.5	1.5	0.7
% mature (of live)	0	0	3.6	1.9	1.2	0.8	3.4	1.7
AREA OF PINEYARD	**4.67 km^2**		**11.50 km^2**		**1.07 km^2**		**17.23 km^2**	

Table 4.3: Population estimates, with standard error of means, of *Pinus caribaea* var. *bahamensis*, in the Turks and Caicos Islands mapped pineyard, by island.

From the estimates provided, and from Figure 4.3, it can be seen that there is a large disparity between the estimated numbers of both live pines and dead pines across the islands. Middle Caicos contains the largest number of pines, both live and dead, while Pine Cay has the least. While this would be expected due to the size difference between the pineyards, it is also due to differences in density. North and Middle Caicos both have a higher estimate of dead pines than live pines, which is what is expected from observation; Pine Cay has less than half the number of dead pines compared to those alive.

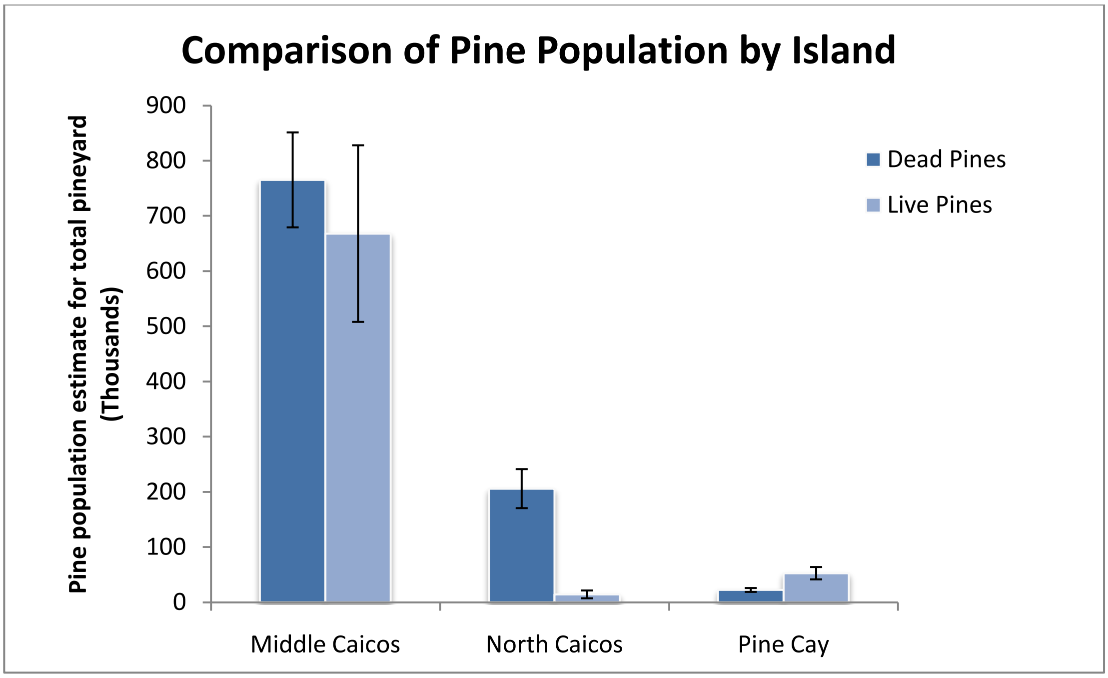

Figure 4.3: Comparison of pine estimates by island

When breaking down the number of live pine trees into mature and immature (Figure 4.4) it is illustrated that the majority of the live trees are immature and in fact the number of mature trees makes up a small proportion (0% in North Caicos; 3.64 % in Middle Caicos and 1.24 % in Pine Cay). Although the population estimate of live trees differs between islands, all island pineyards are comprised mainly of immature pine trees.

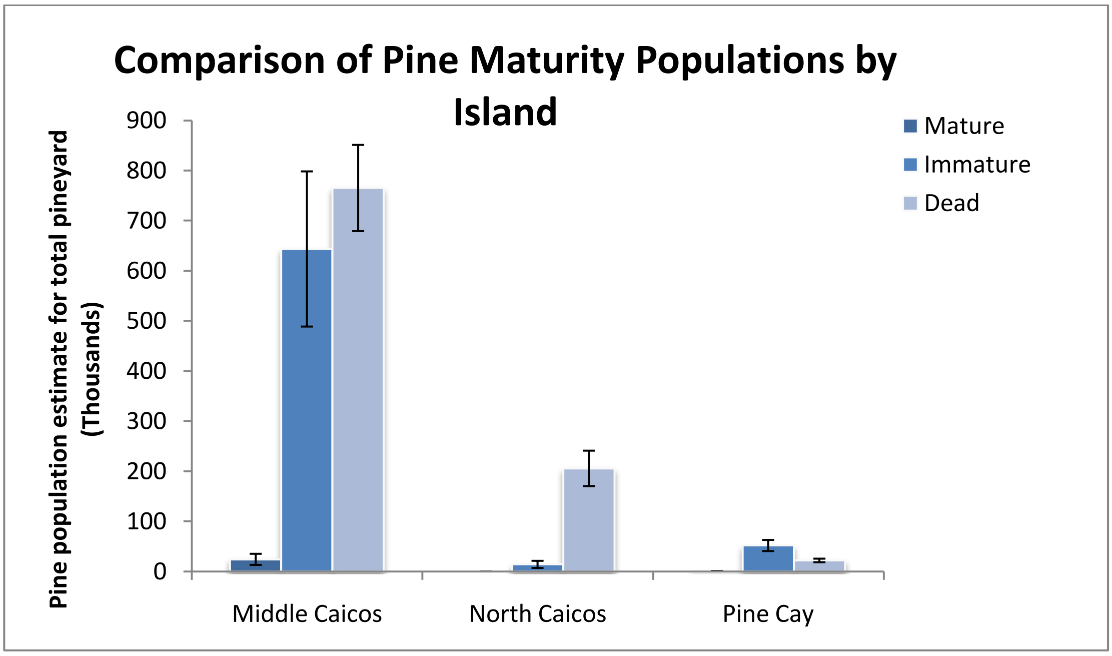

Figure 4.4: Population estimates of the Caribbean pine, across the three islands, separated by age class.

In terms of the number of trees which have been killed under the influence of the invasive scale insect and burning, the largest proportion of dead trees can be seen in North Caicos (Figure 4.5). In North Caicos 93.5% of recorded tress are dead, in Middle Caicos this number is 53.4% and Pine Cay has 29.7% of dead pine compared to the total number of pines. Despite the variance in percentage of pine trres which are dead, all three islands share a very large number of estimated decline of mature trees; 100% on North Caicos, 96.9% on North Caicos and 97.1% on Pine Cay.

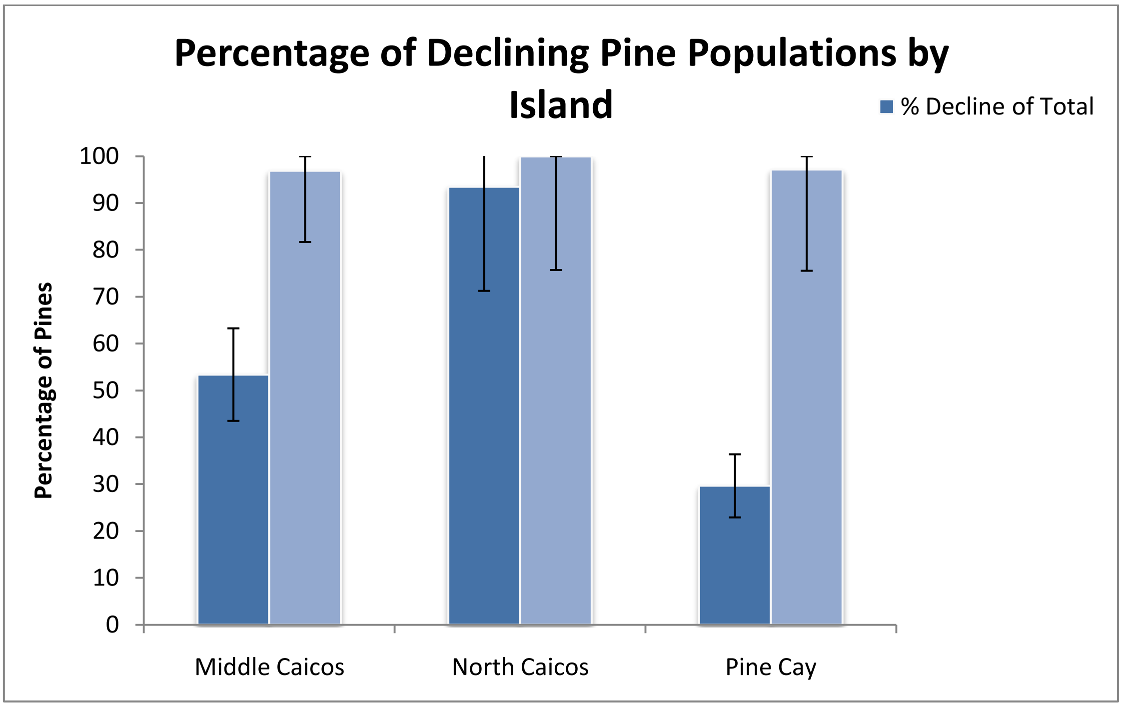

Figure 4.5: Estimates of the total decline of the Caribbean pine and the percent of mature trees

4.3 Influence of the Caribbean Pine on the Surrounding Plant Community

4.3.1 Species Models

From results testing the possible influence of pine density on the local plant species richness it is possible to deduce that there is a significant effect of the density of dead pine trees on the number of plant species (χ^2 = 6.75; d.f = 1; $p < 0.001$). However, the number of mature trees has no significant influence on the plant species richness in the Turks and Caicos pineyards (χ^2 = 0.06; d.f = 1; $p < 0.81$). Illustrated in Figure 4.6, the number of plant species present significantly decreases with an increase in the number of dead pine trees present.

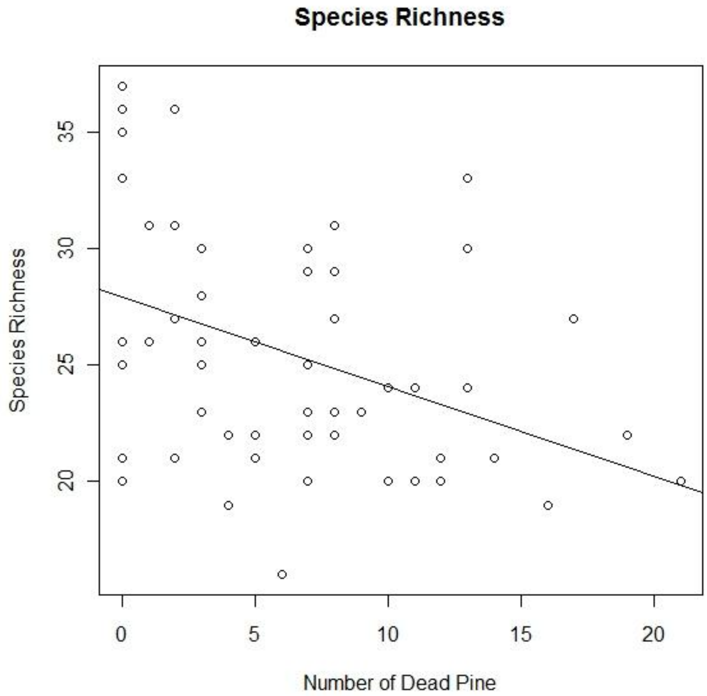

Figure 4.6: Plot of plant species richness against the density of dead pines.

Models show that the density of dead pines has a significant effect on the abundance of neither palm species, *Sabal palmetto* (χ^2 = 3.174, d.f = 1, $p < 0.075$) or *Leucothrinax morrisii* (χ^2 = 0.795, d.f = 1, $p < 0.372$). Figure 4.7 suggests there may be a slight trend between *S. palmetto* and the number of dead pine, with the abundance of *S palmetto* increasing as the number of dead pines increase. There is also a slight increasing trend of *S. palmetto* as mature pines decreases, although there is no significant influence of the density of mature pine on species richness (χ^2 = 0.023, d.f = 1, $p < 0.879$) . Although not significant, it may be the case that with a larger sample size this interaction may be significant. The plots of *L. morrisii* abundance support the statistics that it is under no significant influence of pine density, dead or mature (χ^2 = 0.031, d.f = 1, $p < 0.859$).

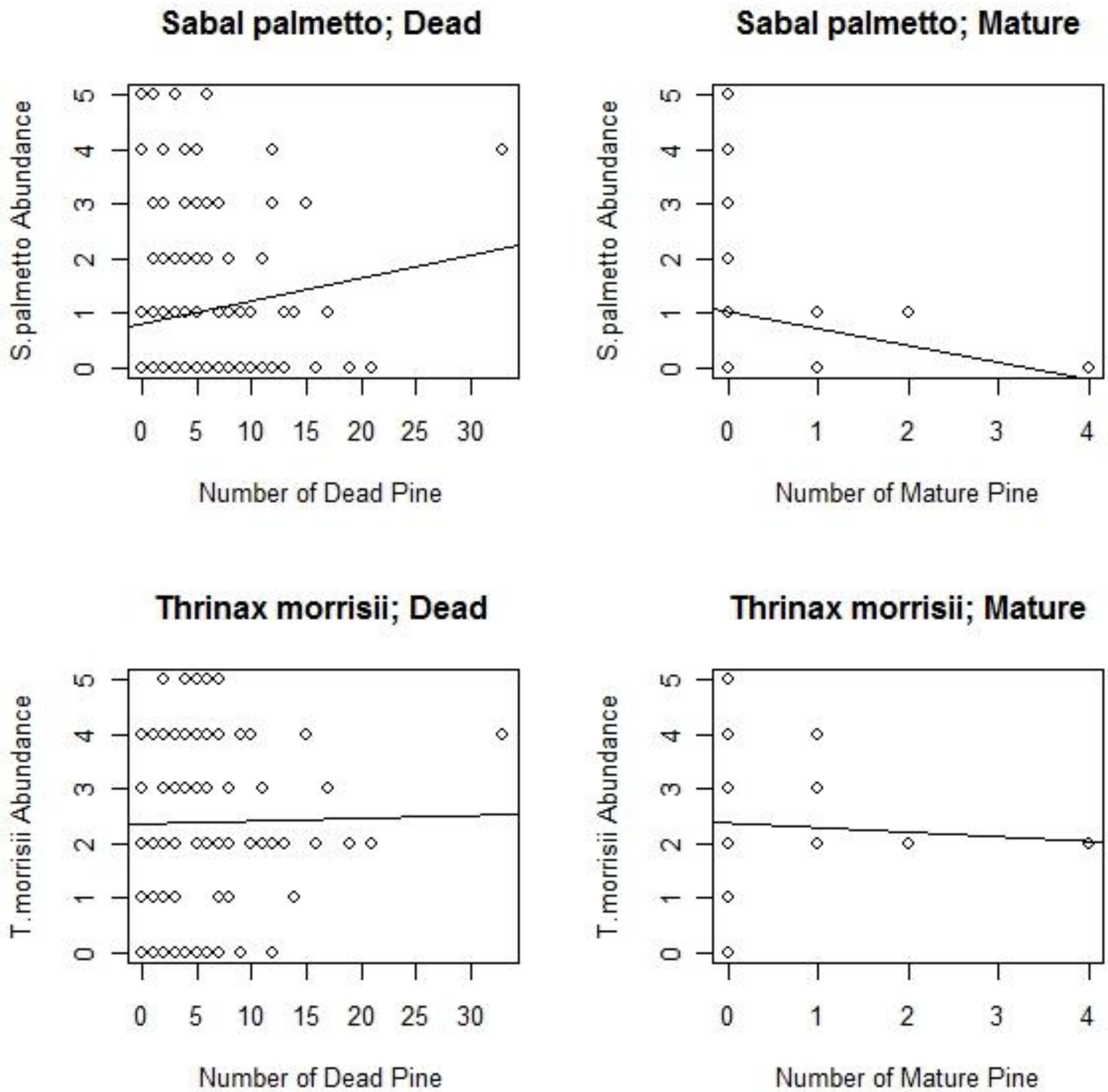

Figure 4.7: Plots of the palm species, *Sabal palmetto* and *Leucothrinax morrisii* (formerly *Thrinax morrisii* as labelled here), interaction with numbers of mature and dead pines.

Species which were found to be common in the pineyards are: *Acacia choriophylla*; *Angadenia berteroi*; *Cassytha filiformis*; *Coccoloba diversifolia*; *Coccoloba uvifera*; *Erithalis fructicosa*; *Ernodea serratifolia*; *Metopium toxiferum*; *Randia aculeata*; *Rhynchospora floridensis*; *Heterosavia bahamensis*; *Swietenia mahogany*; *Tabebuia bahamensis*; *Leucothrinax morrisii.* Many species which are characteristically found in the pineyard but not "common" can be found in the full list of all species recorded in the TCI pineyard habitat (Appendix. 4). Of these common species both *Heterosavia bahamensis* and *Angadenia berteroi* are only found in areas associated with pine. In the full list of species present, those which are only found in the pineyard are *Galactia rudolphioides* and *Myrica cerifera.*

GLM results show that species interactions and the influence of mature pines on species composition were not significant (d.f = 107; dev = -138.78; $p < 0.021$), however there is a significant influence of the number of dead pines on local species composition (d.f = -107; dev = -356.1; $p < 0.001$). In this case the p value deemed as significant is reduced to <0.01, due to testing the interactions of 108 species, which increases the chances of a type I error.

Table 4.4 contains the outputs of five species which were found to have a significant relationship with the number of dead pines. Only one species abundance recorded had a significant relationship to the <0.01 level, and this was *Pinus caribaea* var*. bahamensis,* which is to be expected. It was for this reason that species significant to the <0.05 were included. Under the same GLM no plant species were found to have a significant relationship with the number of mature pines (to the <0.05 level), interestingly not even the Caribbean pine itself, suggesting that insignificance may be due to the small number of sample plots containing mature trees and not necessarily true in reality.

Table 4.4: Significant results of a General Linear Model of interactions between 108 plant species abundance and the number of dead pine trees (Model = GLM; Error=Transect; Family=Poisson).

Species	Estimate	Std. Error	z value	Pr(>|z|)	Significance
Evolvulus arbuscula	-1.08E+00	4.39E-01	-2.466	0.013662	<0.05
Coccoloba krugii	-2.61E-01	1.12E-01	-2.329	0.019842	<0.05
Gochnatia paucifloscula	-5.08E-01	2.33E-01	-2.184	0.028941	<0.05
Pinus caribaea* var. *bahamensis	1.25E-01	4.38E-02	2.853	0.004336	<0.00
Scleria lithosperma	-5.67E-01	2.59E-01	-2.187	0.028715	<0.05

Plots of species abundance against the number of dead pine trees (Figure 4.4) suggests that small numbers of each of these species, excluding *P. Caribaea* var*. bahamensis,* are found when there is a low number of dead pine trees. Conversely to what may be expected the abundance of *P. Caribaea* var*. bahamensis* increases as the number of dead pine trees increase. This suggests the abundance largely represents the number of seedlings which are growing due to an empty canopy layer.

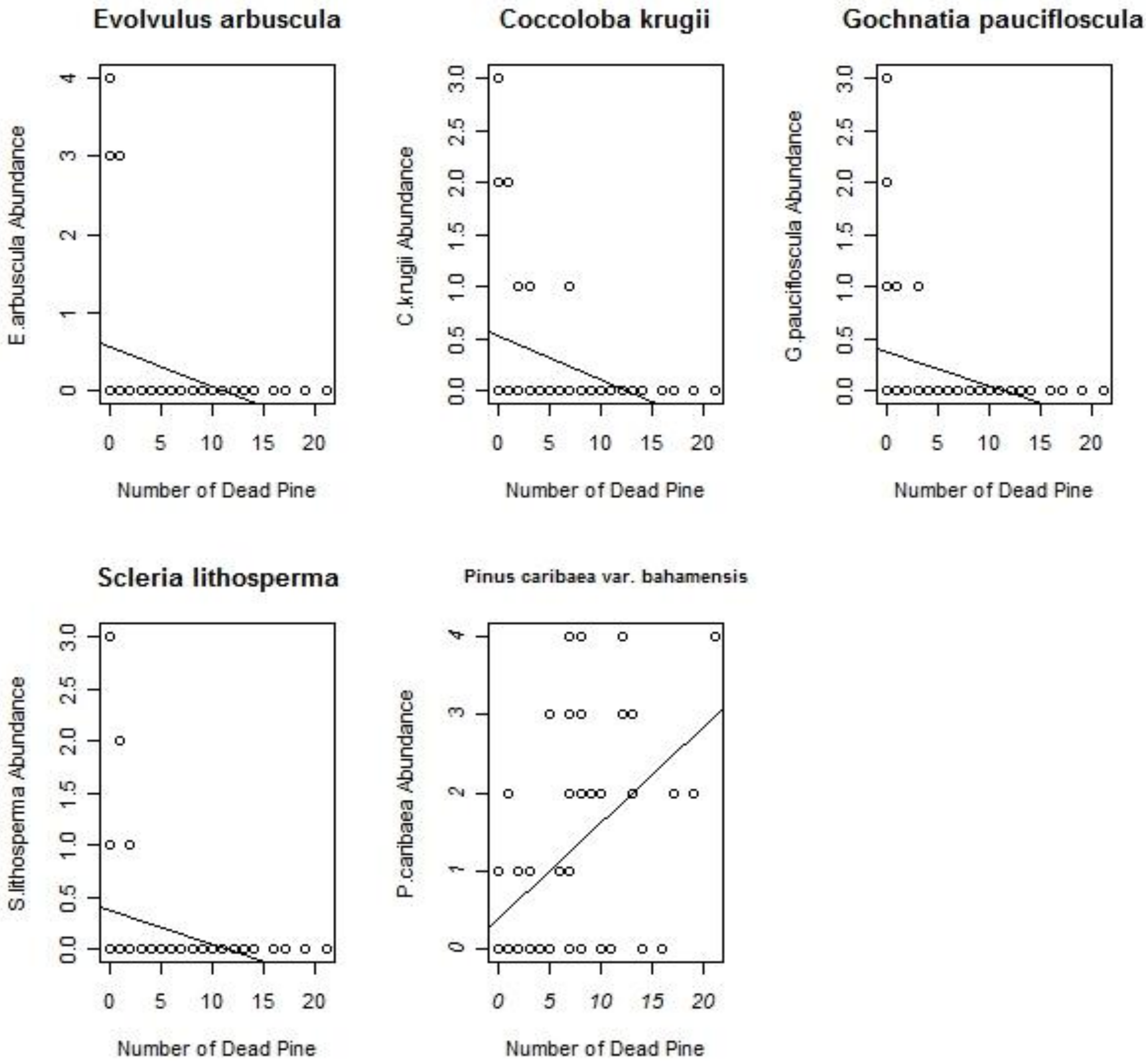

Figure 4.8: Plots of the five species which have a significant relationship with the number of dead pines, against number of dead pines.

4.3.2 Ordination

The ordination plots (Figure 4.10) show the similarity of each sampling plot in relation to others, on terms of species composition and species abundance.

From the similarity of transects plotted (Figure 4.9) it is possible to infer that sampling plots within a transect are likely to have a greater similarity of species composition and abundance with each other than those in another transect. This may suggest that plant species composition varies across the sampled areas of the Middle Caicos pineyard irrespective of the influence of pine density. Some transects are more clustered and isolated than others, for instance transect nine is clearly separated from all other transects, so it can be assumed the plant species composition here is different from that in transect seven, which is also well clustered. There is undeniably separation in transect similarity, with some far more clustered than others. It would be interesting to relate these transects to the sampled pineyard to determine which areas are similar in species composition and which seem to be more distinct.

From Figure 4.10 it is possible to see that the absence of mature pine has a random distribution, showing no similarity between plots and so is unlikely to have any influence on species composition. The presence of mature pines shows some clustering, suggesting that mature trees may extend some influence on species composition, however it is not possible to draw conclusions as only six plots have mature pine tree present.

It is clear to see that some clustering of pine abundance occurs with all the other pine variables, immature, dead, live and total number of pines. From the distribution of similarity highlighting the numbers of dead pines and immature pines, both show a wider random distribution of plot similarity at low densities, but as densities increase clustering is more pronounced, suggesting that at high densities both immature pine and dead pine have effects to make the plant community more homogeneous.

The distribution and similarity of plots for both live and total pine number is similar to those already mentioned. The similarity of trends is due to these variables being an amalgamation of mature and immature pines variables for live pines, and of these and dead pines, for the total number of pines. It is therefore unsurprising that the trends found in the more specific variables can also be seen in the total number of pines and number of live pines. This demonstrates that the trends of pine influence on the surrounding plant species composition and abundance should be tested at smaller resolutions, such as the age classes, to determine the true driving effects of pine densities on the plant community.

Furthermore it is possible to deduce from live pines and total pines, that those plots which lack the presence of pines, of all classes, are more randomly spread and situated in the lower half of the graphs; the opposite of those plots with high pine presence. This may make it possible to speculate that the presence of pines, of any status, creates a more homogeneous plant composition dissimilar to that without the influence of any pine variables. This would confirm the fact that in the absence of pine the plant community is different, and possibly increasingly characteristic of dry tropical forest, rather than composed of typical pineyard species.

The clustering of pine variables is inconclusive as to a relationship with plant species composition but may suggest that, although not significant within statistical models, the Caribbean pine does have an influence on the plant community. However, it is not possible to deduce whether specific pine variables have divergent effects.

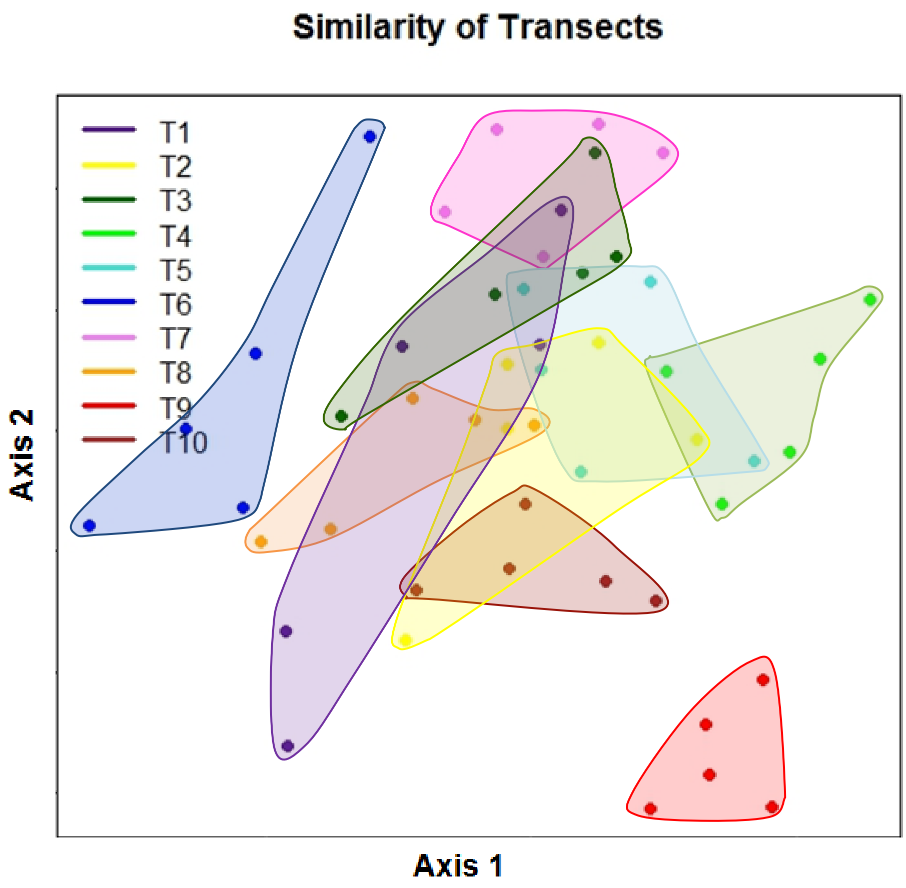

Figure 4.9: Ordination illustrating similarity of species composition and abundance in plots within transects (best stress model = 17.88)

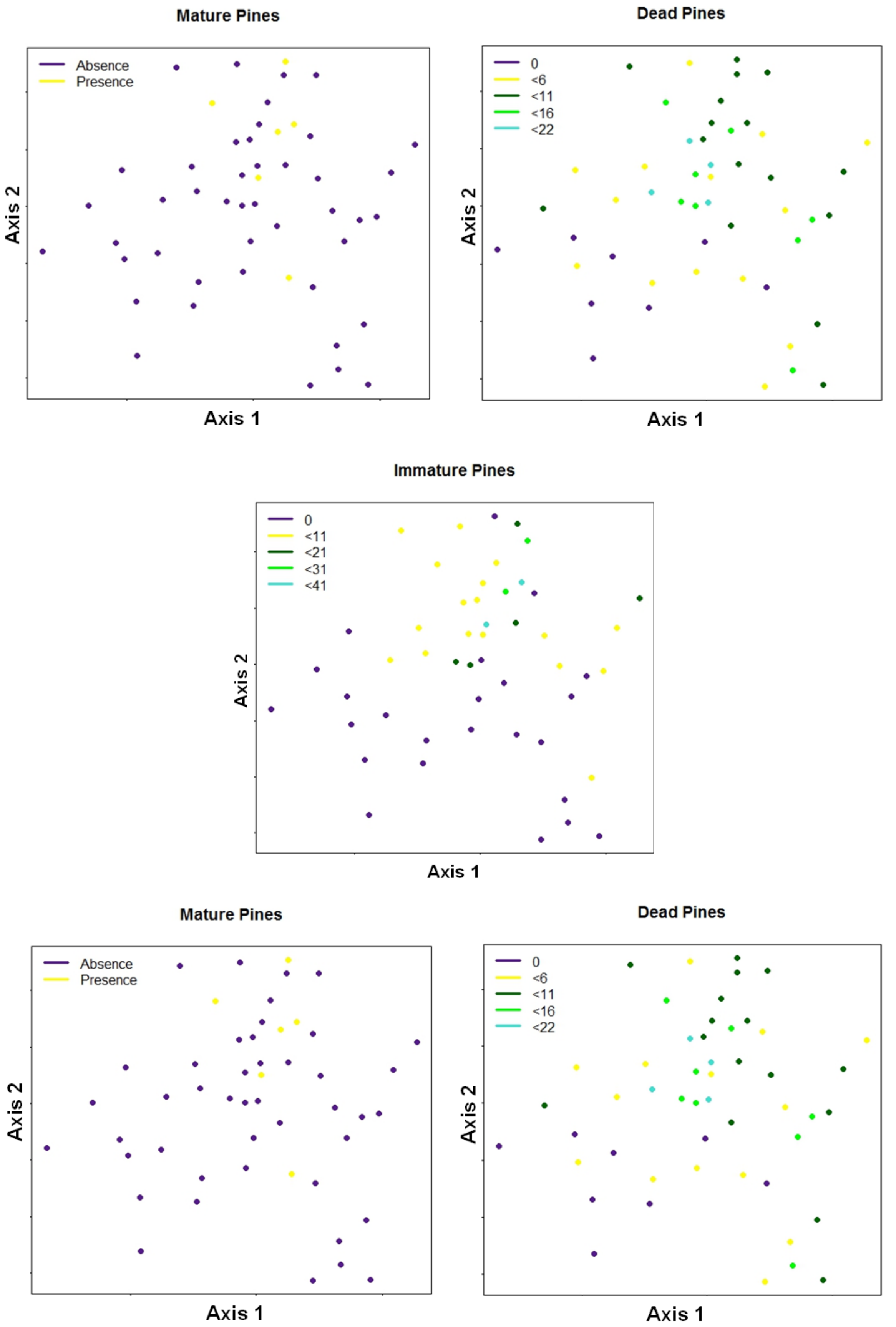

Figure 4.10: Ordination illustrating similarity in plot species composition and abundance in response to pine tree variables (best stress model = 17.88)

5. Discussion

5.1 Investigation of the Effects of Management Strategies on the Caribbean Pine

From the evaluation of the efficacy of PMP treatments in the last year it is possible to address the research questions:

- Have the management strategies employed in the permanent monitoring plots controlled the invasive scale insect?
- What is the best management strategy for safeguarding the remaining pine trees in TCI?

Firstly, it can be answered from data analysis, and from personal observation in the Turks and Caicos Islands pineyards, that the invasive scale insect has not been completely removed in the PMPs by any of the treatments. In fact within all the PMPs across the three islands, irrespective of treatment type, the presence of the invasive scale insect is still extensive.

5.1.1 Plot Monitoring

The comparison of collected data and baseline data shows the degree of efficacy of the treatments and the mean change in the ecological variables as a result of the invasive scale insect infestation. Both the plot data and monitoring of individual trees show the level of scale infection on the pine trees increased in the last year. The analyses also show an interaction between year and treatments. Trends illustrating a large increase in mean scale infestation relative to the other two treatments suggest that broadleaf clearance is ineffective as a treatment to control the invasive scale insect infestation. A significant increase of sooty mould from the baseline tree data (Figure 4.2), with the largest rise also found on those trees treated with broadleaf clearance also supports this assertion. It is interesting to discover that, not only have all management treatments increased the infestation and quantity of sooty mould, but that broadleaf clearance has had a more pronounced influence on the increase than the control treatment. It may be that the actions involved in the broadleaf clearance are having a contrary effect to that desired. It could be, for instance, that the physical clearance of vegetation and close contact with individual pines provides a mechanism for spread of *Tourmeyella parvicornis*. A process such as this fits with the statistics, as both broadleaf clearance & soap spray and the control treatment have less of an influence on both variables mentioned. It is possible that a similar process occurs with the broadleaf clearance & soap spray treatment, but the effect of the soap spray counters the influence of increased transmission of the invasive scale insect between pines.

Mean canopy loss had the largest reduction in the plots under the control treatment and the smallest in those treated with broadleaf clearance. It is interesting that canopy loss has decreased when the levels of scale infestation and sooty mould have increased. It would be expected that if the invasive scale insect directly causes canopy loss that the variables would increase together, not necessarily at the same rate. As the statistics suggest that mean canopy loss is not a function of scale infestation, it can be assumed that the two variables are not directly linked. The results of this study suggest that although the invasive scale insect has a clear influence on the canopy loss of the Caribbean pine, it may not be the dominant factor, but perhaps acts as a facilitator of canopy loss reducing resilience to other environmental stresses. Alternatively, treatments could reduce the environmental stress on the pine trees causing a consequential reduction in canopy loss c allowing a increase in scale infestation due to a healthier canopy. However, as control treatments saw a similar effect this hypothesis is unlikely.

To further support the judgement of broadleaf clearance as the least effective treatment tested, tree mortality significantly increased from last year, which is in itself unsurprising considering the comparison to baseline data. However the largest mean mortality occurs in broadleaf clearance treatment plots. The difference between treatments is significant, with the control treatment having the least influence on tree mortality. It may be considered that, after one year of monitoring, the control treatment may be only slightly behind the broadleaf clearance & soap spray in terms of the relative efficacy of treatments.

The monitoring of individual pines shows a significant change in height and DBH within the last year; however the visual data proves ambiguous, with no clear trends. Conversely, the plot data shows a non-significant decrease in both pine height and DBH of the tallest tree within each PMP, suggesting a lack of continuity between data collection last year and this year.

In terms of relative efficacy, it can be deemed that broadleaf clearance is the poorest and broadleaf clearance and soap spray is the best treatment, but not to a considerable degree. It is very well to talk of relative efficacy, but regarding efficiency as a control treatment, none of the treatments have been effective at reducing the level of scale infestation or sooty mould, but have increased levels instead. It is therefore possible to answer the research question, “Have the management strategies employed in the permanent monitoring plots controlled the invasive scale insect?” with a negative response. Yet, it is unlikely that this is an achievable outcome within the monitoring plots, due to high re-colonisation rates, resulting from their small size and the large surrounding infestation of *T. parvicornis*. It may be more valuable to ask the question, “Have the management strategies employed in the permanent monitoring plots reduced the incidence or effects of the invasive scale insect?” The answer to this question is also no, as no significant efficacy of treatments decreasing the level of infestation, or subsequent effects, have occurred. In fact the opposite has arisen. Furthermore, this makes it difficult to ascertain “the best management strategy for safeguarding the remaining pine trees in TCI”. It may be plausible that none of the treatments are credible or effective for long-term Caribbean pine conservation. However, it is important to consider that these conclusions have been drawn after only one year of monitoring. It is important to consider that although interesting trends have been revealed, it may be prudent to wait for a second year of monitoring, at least, to confirm these findings before they are used as guidelines for management.

5.1.2 Strengths and Limitations

The over-riding weakness of the results presented is their basis on only one year of monitoring, which may be suitable to highlight trends, but not enough to directly inform management strategies. This is especially true when considering that only one or two applications of treatments took place within the time-span of a year, meaning that continued application may show more pronounced effects. Furthermore, the staff of the CPRP did not notice any significant die-off of the scale insect after the application of soap spray (Manco. B. N., *pers. comm*.); an experimental double-concentrated trial using the *ex-situ* collection of pine trees has had a more observable effect. Therefore, in the next year, stronger and more frequent treatment application may be required for the effects to become apparent. As the collected data and study results will contribute to a long-term Caribbean Pine monitoring, they will be used in determining effective control treatments for the invasive scale insect and informing management decisions in the future.

As stated above the non-significant reduction in the height and DBH of the tallest trees with each plot highlights the issue of inconsistency of data collection between years. This issue is unanticipated, considering all efforts were made to ensure consistency between dataset collections; such as preliminary data collection practice to refine estimates and scaling of recorded variables and competent use of equipment. Consequently, this discrepancy must be taken into account, for both the variables stated and others, when considering the results.

5.1.3 Conservation Implications and Recommendations

The research into an effective treatment for the control of the invasive scale insect is a priority for the conservation of the Caribbean pine. If an effective control mechanism is realised this will be used to clear areas of pineyard of the invasive scale insect allowing the reintroduction of the *ex-situ* collection (Manco. B. N., *pers. comm*.). However, it must be considered whether this is feasible and effectual for the recovery of the Caribbean pine in the Turks and Caicos Islands. Bearing in mind the rate of spread of the invasive scale insect from its believed introduction in Pine Cay, the probability of maintaining an area of scale-free pineyard is highly unlikely, without continuous and vigorous treatment application. In the long-term is this small population of re-introduced pine trees, under intensive management, contributing to the "recovery of the Caribbean pine and pineyard habitat"? Furthermore, is this investment in prolonged management of this small scale-free population worthwhile?

It may be sensible to consider the eradication of the invasive scale insect from the extent of the pineyard, as in reality this may be the only suitable means of recovering the Caribbean pine in TCI. However, the CPRP can only carry out work within the scope of available resources, and do not see the complete control of the invasive scale insect as either economically or ecologically feasible at this time (Manco. B. N., *pers. comm*.). Using the population estimates within this study, a calculation of expenditure of soap spray would be $75,700 alone. Furthermore, the complete eradication of the invasive scale insect would only be successful and cost-effective if adequate controls are put in place to prevent any future re-introduction.

Irrespective of plant species affected, an increase in pest control and phytosanitary regulations must become a priority for the Turks and Caicos Islands to prevent future introductions of invasive species with the potential to damage ecosystems in the capacity of the invasive scale insect. Moreover, considering the destruction of the pineyards within Turks and Caicos, and possible extirpation of the Caribbean pine, it is important to protect the Bahamian populations through taking all precautions to prevent an introduction of *T. parvicornis* and other potentially damaging pests.

Taking this into consideration, the development of effective regulation is both crucial for the long-term international protection of the Caribbean pine and for the conservation of other native and endemic flora. The need to enact legislation to prevent the introduction of alien invasive species by regulatory and other means, in support of the Convention on Biological Diversity, was highlighted in The National Invasive Species Strategy for the Bahamas (BEST Commission, 2003). It is clear that the threat of the alien and invasive species is understood across the international community; however effective regulation concerning protective measures, in the Bahamas, is still lacking. This is also true of the Turks and Caicos Islands, which need to take heed from the introduction of *T. parvicornis* to the pineyard ecosystem. Both countries are party to the CBD and consequently the GSPC, which have targets to reduce the spread and introductions of invasive alien species through effective legislation. Regulation of invasive and alien species needs to be a priority in the Bahamas, in additon to TCI, for the long-term conservation of the Caribbean pine. It is important to maintain the

International Pine Scale working group to prevent and manage the spread of *Toumeyella parvicornis* Cockerell to other Caribbean pine populations (Global Invasive Species Database, 2010).

5.2 Determination of a Caribbean pine population estimate

Before this study there had been no assessments to establish a population estimate of the Caribbean pine in the Turks and Caicos Islands, nor estimates of decline as a result of the invasive scale insect, *T. parvicornis*. This study goes half way to achieving the research aim of developing an accurate population estimate. Declaring the estimates as accurate would be unfounded and speculative, considering the limitations of their formation. Yet, despite the limitations, the methods are sufficiently robust to warrant population estimates to be used to inform CPRP in management decisions and as an approximate set of figures for use in future research.

5.2.1 Pineyard age structure

Middle Caicos has the largest population of pine by a considerable amount, the main reason being due to a larger pineyard relative to the other islands. The number of live pines is only ~ 100,000 less than the number of dead pines; an estimated decline of 53.4%. From observation of the sparse pineyard this may seem like an over estimate, but only 3.6% of the live pines are mature. The large number of seedlings and saplings present in the Middle Caicos show early stage succession of the pineyard habitat, after burning in the last decade.

North Caicos shows a different structure with a much higher number of dead pines, making it the pineyard with the largest decline. No mature trees were sampled, creating an estimate of 100% decline of mature trees. Having seen a small number of mature trees in field, this estimate is inaccurate. In addition there are many less seedlings in North Caicos than either of the other pineyards. A possible reason could be due to the high density and abundance of palm species, *Sabal palmetto* and *Leucothrinax morissii*, preventing canopy gaps, which would otherwise allow regeneration.

The Pine Cay population, from personal observation, seems to be in a more promising state. The population estimates indicate more live trees than dead, although the majority of these are immature. However, the number of immature trees in Pine Cay is much less than in Middle Caicos. Mature trees look, in general, larger and healthier than in North or Middle Caicos. The pineyard in Pine Cay, of all three islands looks the most representative of a healthy pineyard ecosystem, leading to the inference that the Caribbean pine population will have the best chance of survival here.

5.2.2 Strengths and Limitations

Within the sampled sections of the mapped pineyard good coverage of transects were achieved, allowing for variation in pine density and the calculation of accurate population estimates. The relative ratios of dead pines to live pines should be reasonably accurate however the accuracy of the estimates is compromised by not sampling the whole pineyard on North or Middle Caicos. Poor accessibility to large areas of pineyard on both islands suggests that the estimates may not be representative of the whole pineyards, only the localised areas sampled (see Appendix 3).

An inherent problem with the data collected in the pineyard is the lack of mature trees, making population estimates difficult; this lead to an untruthful estimate of zero mature trees in the North Caicos pineyard. The high level of variation of pines throughout the pineyard requires a larger sample size than the time allotted for this study would allow. A further complication influencing the outcome of mature tree population estimates is the qualification of "mature". In this study trees with cones were recorded as being mature, however this criteria does not include ages of cones, and so it cannot be assumed that all mature trees are reproductive. It is likely that the reproductive population is significantly lower than the population of mature pines.

A final limitation affecting the population estimates in this study is the quality of the mapping used to determine pineyard area. When undertaking field data collection, areas of mapped pineyard were in fact dry tropical forest and vice-versa. Without further ground truthing of the pineyard maps, the accuracy of the extent of the pineyards cannot be assumed exact.

5.2.3 Conservation Implications and Recommendations

The majority of live pines are immature across all three islands and all pineyard have a huge decline of mature trees (all over 96%). This holds large implications in terms of the pineyard fire regime. As recent fires have caused the growth of many seedlings, fires too frequently may kill large numbers of seedlings that are not yet large enough to tolerate the burning. An anthropogenic fire occurred in Ready Money, in North Caicos, creating an area almost void of pine seedlings. If this was to occur in Middle Caicos a large proportion of the total pine population could be removed, having significant consequences on the Caribbean pine population in the Turks and Caicos Islands. As the level of seed production, and consequently level of regeneration, is unknown frequent fires could exacerbate the speed of pine decline and ultimately the destruction of the pineyard ecosystem. The potential consequences of anthropogenic fire on a pineyard ecosystem largely composed of immature individuals' calls for urgent fire management.

Fire management has been proposed in the CPRP Action Plan (DECR, 2010), with the intention to create a fire management plan within the coming year. Currently plans are underway for a prescribed burn and fire monitoring within the next year (Hamilton. M. *pers. comm.*) using international expertise. Research concerning fire management of Caribbean pine is more established within the Bahamas than TCI. International collaboration incorporating both fire management and conservation may be necessary for the future.

The development of a fire management plan is necessary for successful management of a fire dependent ecosystem (O'Brien et al 2008); however, it is also important to address the current threats of imminent fire, as the cost may be disastrous. Since agricultural fires were the origin of the last two pineyard burning events, it is essential to tackle fire use within the community, as well as developing ecological management plans. The use of fire in agriculture is illegal in the Turks and Caicos but still common, suggesting the need for the enforcement of current legislation. Personal communication with many farming residents of North and Middle Caicos has highlighted the ignorance of many island inhabitants as to the rules and regulations of fire use. It is clear more needs to be done in order to prevent the use of fire in agriculture close to the pineyards. Furthermore, the conservation of the Caribbean pine is important to the majority of residents, many of whom would be willing to support the prevention of fire use close to and around the pineyards, to protect their national tree. Evidently a social education and awareness program, emphasising the plight of the Caribbean pine and the potential consequences of fire use in agriculture, in addition to regulation, could have benefits for the long-term conservation of Caribbean pine. The education and communication of the importance of plant diversity and its conservation is a target outlined in the GSPC. A public-awareness program would be aiding the conservation of the pine but also be contributing to international conservation targets. Long-term strategic planning from the CPRP integrating many disciplines may be the best approach for effective conservation of the Caribbean pine in the Turks and Caicos Islands.

5.3 Investigation of the relationship between the Caribbean pine and the surrounding plant community

The influence of the invasive scale insect goes beyond the Caribbean pine, a keystone species, and affects the whole pineyard ecosystem. To understand the effects on the plant community, this study aims to increase the understanding of the role the pine plays as the dominant species and how the consequential effects of the invasive scale insect are changing the local plant composition.

5.3.1 Influence of Caribbean Pine

The number of dead trees influenced the abundance of five species, *Evolvulus arbuscula*, *Coccoloba krugii*, *Gochnatia paucifloscula*, *Scleria lithosperma*, which were only found in plots with a small number of dead pine trees, and *Pinus caribaea* var. *bahamensis*, which increased with the number of dead pines. A likely explanation for this is due to seedling regeneration in areas with canopy gaps. In addition the high density of dead pine caused a decrease of species richness in Middle Caicos, supporting the suggestion that succession is in early stages, characterised by high pine regeneration and a high diversity of herbaceous species (US Fish and Wildlife Service, 2007). It can therefore be assumed that the Caribbean pine has significant effects on the native flora in the pineyard, which may change as the pine declines in number. Since the influence of the invasive scale insect is having wider consequences across the pineyard, the ecosystem must be considered as a whole, rather than restricted to the Caribbean pine in isolation.

An increasing trend of *Sabal palmetto* abundance with an increase in density of dead pines, but no trend for *Leucothrinax morissii,* means it could be possible that an increase in dead pine influences both species, which is what is expected from observation, but that the dominance of *S. palmetto* prevents this trend being seen in *L. morissii*. North Caicos has the largest density of palm, exclusively *S. palmetto*; the area of this pineyard which burned in 2009, Ready Money, has a very high abundance. It can be inferred that the relationship is not direct and perhaps more complicated than expected, leaving the question of, whether pine density influences the abundance of palm species, unanswered.

Transects show a dissimilarity suggesting that plant species composition and abundance varies within the Middle Caicos pineyard. It would be interesting to develop a species map illustrating the presence of the less common species and those species restricted to the pineyard; this would be especially useful if compared to an invasive scale insect impact map, to develop priority areas for intervention.

In high densities both dead and immature pines, cause the plant community to become more homogeneous, suggesting that in wide spread areas of high pine decline some plant species may become rarer due the community becoming more homogeneous. It may be possible to deduce that density of dead immature pines have an influence to increase species diversity and to make the composition less variable. Furthermore it is clear that the plant community is different between those areas with high numbers of pine and those that contain none, answering the last research question of this study. It is clear that pine densities are capable of driving community change; however more analysis is needed to determine the specific effects on species.

5.3.2 Strengths and Limitations

The first limitation is that time only allowed the species composition and abundance to be recorded on Middle Caicos, and not all three islands. From the species list the composition of the pineyard in Middle Caicos can be determined however, it cannot be assumed this is the same across the whole pineyard extent in TCI. To really understand the compositional change and the effects of both the pine and the invasive scale insect on the plant community, it is necessary to gain species data for all three pineyards. Furthermore, for this reason is not possible to determine the succession of the plant composition, leaving this research question unanswered.

As discussed above, the lack of mature trees within the sampled plots may be the reason for no significance of mature pines influencing species richness or any of the species tested. To adequately test the influence of mature pine trees further sampling must be done. Furthermore, wider distinction of the variables may be necessary to effectively determine the influence of pine. For instance, in the criteria of this study immature trees may be a similar size to mature, but are categorised as immature due to lack of cones. In future studies it may be sensible to classify these separately, as their influence is likely to be more similar to a mature pine than an immature pine.

5.3.3 Conservation Implications and Recommendations

It can be qualified, if not empirically described, that the decline of the Caribbean pine in the Turks and Caicos has an influence on the surrounding plant community, in which case this conservation issue must be viewed at ecosystem level rather than at the species level. Management decisions and conservation strategies must be developed which incorporate the Caribbean pine and associated plant species. It is important to consider the consequences of ecosystem change under the influence of the invasive scale insect, both directly and indirectly.

If conservation strategies are not effective at recovering the Caribbean pine before there has been large-scale alteration to the ecosystem, it may be impossible for the few healthy pines surviving, thought to be genetically resilient to the invasive scale insect, to maintain or reverse the plant composition back from dry tropical forest or a high abundance of palms. It could be predicted that without swift wide scale intervention, this is at risk of becoming a reality, in which case it is a bleak outlook for the Caribbean pine and the pineyards in the Turks and Caicos Islands. It is therefore imperative that more research into this area is undertaken before it becomes too late.

5.4 Future Research

5.4.1 Pine monitoring

It may be prudent, particularly since the discovery that canopy loss may be linked to environmental variables in combination with the scale insect, to start monitoring the environmental and ecological variables to a greater degree, particularly stressful conditions such as salinity and flood levels. Understanding the full dynamics and relationship between the invasive scale insect and the Caribbean pine is essential for conservation interventions to be successful.

5.4.2 Fire

The undertaking of a social survey, to determine the trends of fire use and opinions of Caribbean pine conservation, may be useful for the development of an educational and awareness campaign. A social survey may be able to inform the creation of such a program and may be able to direct the scheme to where in the community it may be the most beneficial.

It would be wise to increase the research into the effects of fire on the structure and succession of the pineyard. Important areas to evaluate would be effects on species composition, pine seedlings and regeneration and influence on the remaining mature pine trees. Monitoring of both pines and species before and after burning events may increase knowledge of succession in the pineyards and an understanding of how fire will influence ecosystem change in combination with the invasive scale insect. Fire management will be an important strategy for pine conservation, however the dynamics must be clearly understood before such management plans can be developed.

5.4.3 Population estimates

Using the population estimates in this study, in combination with genetic studies, it may be possible to establish the effective population size of the Caribbean pine, and so determine the source population and number of effectively reproducing pine trees. Furthermore, the data collected regarding the presence and age of cones could be utilised to give estimates of reproductivity.

It may be necessary to refine the mapped pineyard habitat, including extensive ground truthing. In many areas cluster of dry tropical forest was present and in pineyard was also found in areas not mapped as pineyard habitat. It may also be useful to determine whether these clusters of habitat opposite habitat types are due to ecosystem change, in which case are these clusters remnant pine populations?

More accurate population estimates could be established by an increased plot sample size; this is especially worthwhile for refining the estimates of mature pines.

5.4.4 Plant community

It is apparent and vital to increase the understanding of species composition and change across all three islands, so plant surveys should be conducted in the pineyards of both North Caicos and Pine Cay. The species composition is different on each island (Manco. B. N. *pers. comm*.), and consequently each pineyard may be affected differently to the influence of the invasive scale insect on the pine. It would be foolish to assume that the plant community observed on Middle Caicos is similar across all three islands. This is especially true considering the different stages of succession between the islands.

A number of interesting areas for future research have been presented in the results of this study. It would be valuable to determine whether the number of dead pines directly influences the number of immature pines due to the presence of canopy gaps; to further investigate the influences of pines variables on species composition, especially density of immature pines; the influence of palm species on the species richness; and determine which plant species are commonly found in relation to which pine variables. All these can be done with data already collected and may increase the understanding of the ecosystem function and dynamics and so inform the creation of management strategies regarding pineyard conservation. It is important to discover the full effects of the invasive scale insect and determine what the ecological cost will be if the Caribbean pine is extirpated from the Turks and Caicos Islands.

5.5 The future of the Caribbean Pine in the Turks and Caicos Islands

The aims and objectives of study have been achieved presenting some interesting and useful findings, however the results clearly highlight the need for further research is considerable and necessary for firm conclusion to be drawn. For successful management and conservation of the Caribbean pine a good understanding of influencing factors is essential. Increased knowledge of environmental dynamics, community effects and the influence of the invasive scale insect is vital for the development of rounded and well-informed management strategies. This study emphasises the current lack of knowledge and the wide scope for future research to inform effective long-term management.

It is important that the attitudes taken to the conservation of the Caribbean pine incorporate all disciplines, including fire management, education and awareness. Conservation must be expanded to encompass the whole ecosystem and the importance of enforced legislation is imperative for the long-term protection of the Caribbean pine internationally.

Permanent monitoring plots for the evaluation of invasive insect control treatments have an essential role within a wide scale conservation approach. Monitoring must be continued in the long-term to establish trends so effective management decisions can be made. The PMPs are the first steps in developing an understanding of the mechanisms and factors influencing the decline of the Caribbean pine and the methods for control of *Toumeyella parvicornis*. However, considering the drastic effects the invasive scale insect has had on the pineyard ecosystem, time is of the essence, decisions must be made and conservation actions put in place sooner rather than later, suggesting the need for long-term adaptive management. This study highlights the need for integrated and multi-disciplinary management strategies to ensure the effective and long-term conservation of the Caribbean pine in the Turks and Caicos Islands.

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7. Appendices

Appendix 1: Caicos Pine Recovery Project Data Collection Standards

Table 7.1: Caicos Pine Recovery Project Data Collection Standards

Field Name	Field Description
Unique identifier	Unique ID composed of '"DDMMYY" + "_" + "INITIALS" + "_" + "TYPE" + "_" + NUMBER'"
Collector or Recorder name(s)	Surnames first, followed by a comma and a space, then initials (uppercase) followed by a full stop. In the field, initials can be used to save time then updated in RDE.
Monitoring point number	Accepted number for a given permanent sampling plot/point
Type of record	Single letter to represent the type of botanical record (V=Voucher; O=Observation; L=Literature)
Coded category of material	Used to indicate the category of data/material you are describing.
Additional (team) collectors	Additional collectors should be entered here and each name separated by ';'.
Kew Geographic Region	Use Kew herbarium geographic region code
Country of collection	Store valid country names here. For the UKOTs this will be the name of the territory.
Major country division	The major division. For the UKOTs, this is either the name of the Island the specimen was collected on or it is left blank.
Minor country division	Minor area is a division of the country/island equivalent to region or a defined boundary.
Gazetteer	The gazetteer field is used to store the name of the nearest mapable place to the collection site. This may be a small town, a village, a spring. The smaller the place is, the better the resolution.

Sample area	Size of sample area recorded in meters.
Habitat Description	Defined text description of the habitat.
Geology descriptor	Defined text description of the geology.
Soil/substrate for the collection site	Defined text description of the soil/substrate.
Latitude in decimal degrees	Use up to 8 decimal places
N or S	North or south of equator.
Longitude in decimal degrees	Use up to 8 decimal places
E or W	East or west of Greenwich meridian.
Datum used to record lat/long	Datum used by the GPS to record coordinates.
Lat/Long source code	Source of coordinate information: Label, Map estimate, 'GPS (before 2000)', GPS, External Gazetteer, Internal Gazetteer, Literature, Quadrate Coordinates, Estimate from gazetteer & bearing calculation.
Lat/Long units	Units that the Latitude and Longitude are recorded in.
Error Diameter in kms	The error associated with the Lat / Long, which is dependent on the source of the georeference.
Generated date field	Used by ArcPad to automatically generate the date from calendar selection
Family	The family name appropriate to the Genus with capital of first letter only. If the family is unknown leave blank.
Field for recording species occurrence at a BAP/VAP/Transect	This field must contain a validly published species name including the genus and specific epithet.
Common name (s)	Accepted common name. If there is more than one name, separate the names with a ",".
Plant habit	Tree/Sapling/Seedling.
Plant Description	Free text description of the plant in the following sequence: Life Form; Size; Leaves; Stems; Flowers; Fruits; Bark; Other unique

	characters…
Flowering information	Record whether specimen is in flower/reproducing.
Fruiting information.	Record here whether specimen is in fruit/reproducing.
General notes	Record here any additional information that is not recorded elsewhere.
Abundance Estimate	Using a 0 - 5 scale, record if the species local abundance: 0 = absence; 5 = dominant.
Number of mature individuals	Number representing the mature individuals.
Recruiting population	Indicates if species is successfully recruiting.
Height of Canopy	Number representing average height (meters) of vegetation surrounding collection point.
Canopy density/amount of sun exposure	Number representing percentage of canopy cover of vegetation surrounding collection point.
Ground cover	Number representing percentage of ground cover of vegetation at collection point.
Level of Disturbance	Number representing disturbance observed at/surrounding collection point.
Threats observed for this species	Description of any threats observed for the species in that locality. Refer to standards
DNA collection	Indicates if material was collected to make a DNA collection.
Photos taken of the specimen	Indicates that a photo was taken when the collection was made.
Unique identifier of the photo taken	Unique ID usually refers to the image number
Pine tortoise scale infestation	Indicates whether pine tortoise scale is present or absent from the plot.
Level of Pine tortoise scale infestation	Indicates the level of Pine tortoise scale infestation on a scale from 0 to 5, with 0 being no visible scale and 5 being totally infested
Canopy damage caused by Pine tortoise scale	Indicates the amount of canopy damage due to Pine tortoise scale infestation on a scale from 0

infestation	to 5, with 0 being no visible damage and 5 being tree mortality
Sooty mould coverage	Indicates the coverage of sooty mould, recorded as a percentage of the total leaf area covered by mould.
Pine cone development	Indicates the presence and development of pine cones.
Fire damage to vegetation	Indicates the presence of visible fire damage on the vegetation within the plot.
Height of the tallest tree	Indicates the height of the tallest tree in the plot in metres
DBH of the tallest tree	Indicates the DBH of the tallest tree in the plot in centimetres. If tree shorter than DBH, a basal measurement at 4cm is recorded followed by 'b'.

Appendix 2: Mapped Pineyards with Transects and PMPs.

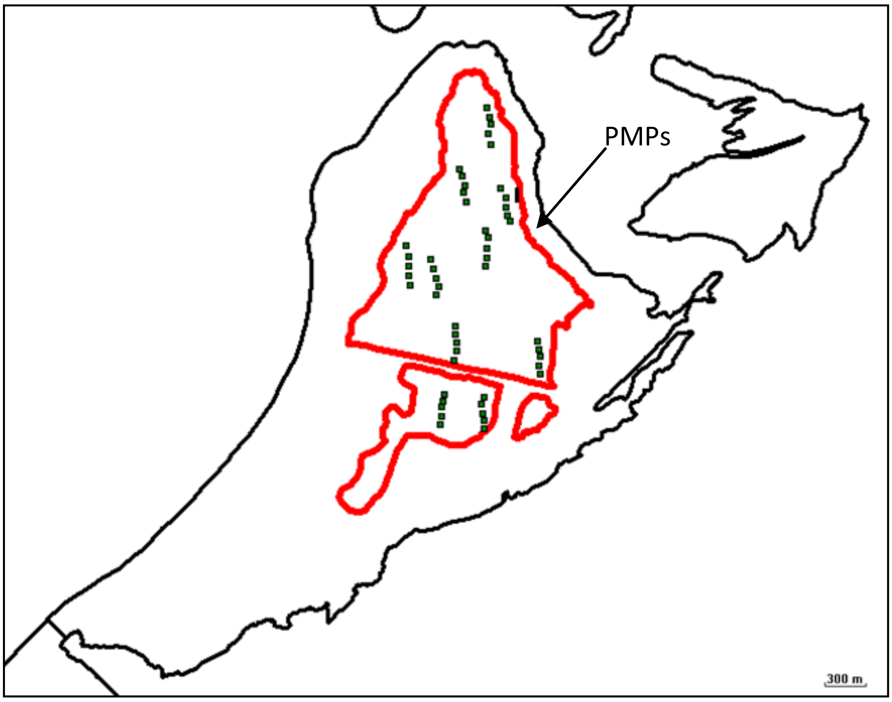

Figure 7.1: Pine Cay mapped pineyard (red), transect plots (green) and PMPs.

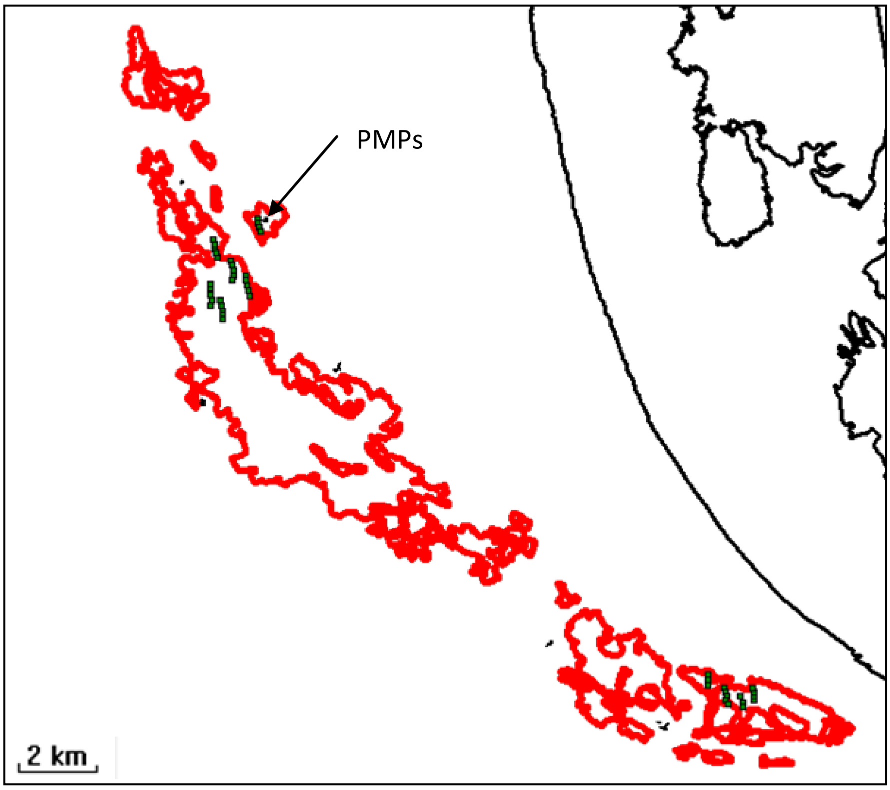

Figure 7.2: North Caicos mapped pineyard (red), transect plots (green) and PMPs.

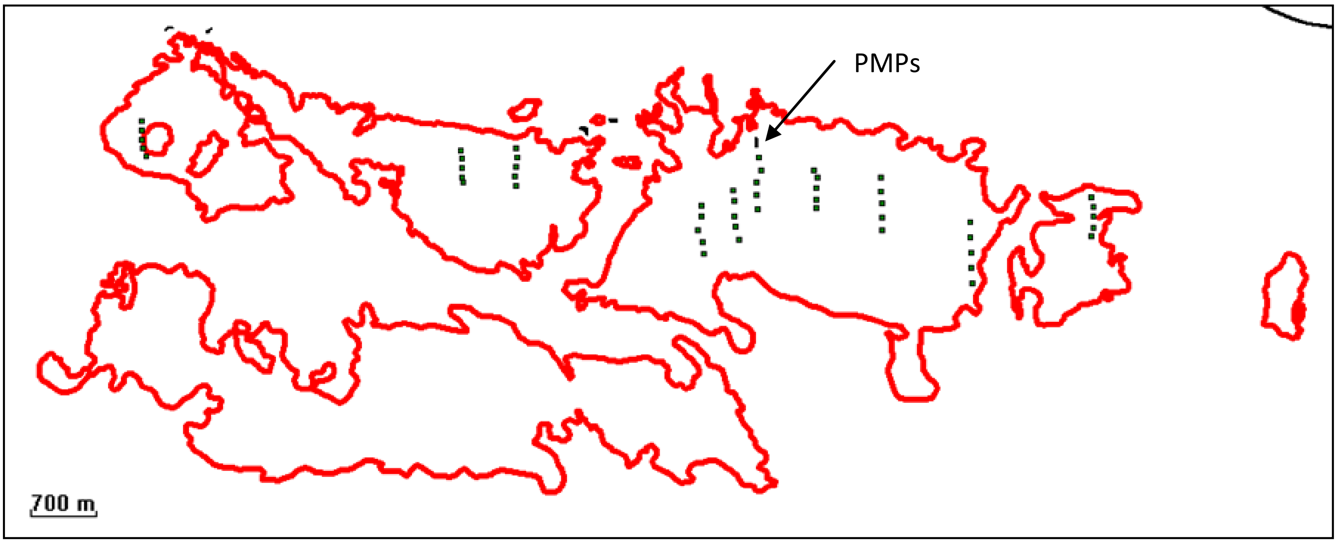

Figure 7.3: Middle Caicos mapped pineyard (red), transect plots (green) and PMPs.

Appendix 3: Full Population Estimates

Table 7.2: Area of mapped pineyard in Turks and Caicos Islands

	Area of mapped polygons sampled (m^2)	Area of mapped pineyard (m^2)
North Caicos	3275426	4669991
Middle Caicos	7062308	11501158
Pine Cay	1043659	1065959

Table 7.3: Estimated average density of Caribbean pine

Island	Pine status	Average density (per 100m²)	SEM (Standard Error of Mean)
Middle Caicos	Mature	0.211538	0.096455
	Immature	5.596154	1.345699
	Dead	6.653846	0.747991
	Live	5.807692	1.391105
	Total	12.46154	1.831199
North Caicos	Mature	0	0
	Immature	0.306122	0.152094
	Dead	4.408163	0.757007
	Live	0.306122	0.152094
	Total	4.714286	0.775913
Pine Cay	Mature	0.061224	0.034604
	Immature	4.877551	1.039866
	Dead	2.081633	0.330991
	Live	4.938776	1.045076
	Total	7.020408	1.139314

Table 7.4: Full population estimates of the Caribbean pine in the Turks and Caicos Islands

		Estimate for area of polygons sampled		Estimate for area of total pineyard	
Island	Pine status	Mean Estimate	SE	Mean Estimate	SE
Middle Caicos	Mature	14939.5	6811.952	24329.37	11093.45
	Immature	395217.6	95037.38	643622.5	154770.9
	Dead	469915.1	52825.43	765269.4	86027.64
	Live	410157.1	98244.1	667951.9	159993.1
	Total	880072.2	129324.9	1433221	210609.1
	% decline (of total)	53.39506	9.878928	53.39506	9.878928
	% decline (of mature)	96.91877	15.23347	96.91877	15.23347
	% mature (of total)	1.697531	0.813225	1.697531	0.813225
	% mature (of live)	3.642384	1.876028	3.642384	1.876028
North Caicos	Mature	0	0	0	0
	Immature	10026.81	4981.741	14295.89	7102.797
	Dead	144386.1	24795.21	205860.8	35352.17
	Live	10026.81	4981.741	14295.89	7102.797
	Total	154412.9	25414.45	220156.7	36235.06
	% decline (of total)	93.50649	22.24192	93.50649	22.24192
	% decline (of mature)	100	24.28607	100	24.28607
	% mature (of total)	0	0	0	0
	% mature (of live)	0	0	0	0

Appendix 4: Species List for the Turks and Caicos Islands Pineyards

Table 7.5: Species List for the Turks and Caicos Islands Pineyards

Species	Number of plots present	Average species abundance
Acacia acuifera	14	0.52
Acacia coriophylla	29	1.06
Agave millspaughii	1	0.02
Amyris elemifera	3	0.08
Andropogon glomeratus	5	0.1
Angadenia berteroi	45	2.14
Ateleia gummifera	3	0.1
Borrichia arborescens	2	0.04
Bourreria ovata	0	0
Brysonima lucida	8	0.26
Bursera simaruba	1	0.04
Buxus bahamensis	5	0.16
Senna mexicana var. chapmanii	32	1.26
Chamaecrista lineata	0	0
Cassytha filiformis	40	1.88
Catesbaea foliosa	4	0.1
Centella asiatica	2	0.04
Centrosema virginianum	1	0.02
Cladium mariscus ssp. jamaicense	21	1.1
Coccoloba diversifolia	32	1.26
Coccoloba krugii	9	0.28
Coccoloba swartzii	8	0.34
Coccoloba uvifera	47	2.32
Conocarpus erectus	23	1.32
Cordia bahamensis	0	0
Crossopetalum rhacoma	14	0.32
Croton lucidus	3	0.1
Cyperus planifolius	1	0.06
Dodonaea viscosa	2	0.04
Drypetes diversifolia	2	0.06
Echites umbellatus	0	0
Eleocharis cellulosa	2	0.08
Eleocharis spp.	1	0.02
Encyclia altisima	17	0.6
Encyclia rufa	8	0.24
Erithalis fruticosa	35	1.46
Ernodea serratifolia	46	2.54
Erythroxylum rotundifolium	3	0.08

Eugenia axillaris	6	0.22
Eugenia sp.	2	0.06
Euphorbia blodgettii	6	0.12
Euphorbia inaguaensis	2	0.04
Euphorbia spp.	1	0.02
Eustachys petraea	4	0.12
Evolvulus arbuscula	5	0.28
Fimbristylis inaguensis	4	0.14
Galactia rudolphioides	2	0.04
Gochnatia paucifloscula	6	0.18
Grass spp.	1	0.02
Guapira discolor	23	0.72
Guapira obtusata	3	0.08
Guettarda eliptica	3	0.08
Guettarda krugii	6	0.2
Guettarda scabra	2	0.06
Gundlachia corymbosa	6	0.26
Gymnanthes lucida	2	0.04
Ipomoea grandifolia	0	0
Jacquemontia havanensis	17	0.48
Jacquinia keyensis	29	1.3
Lasiacis divaricata	0	0
Lepidaploa arbuscula	2	0.06
Lichen	6	0.16
Lysiloma latisiliquum	18	0.68
Malpighia polytricha	1	0.02
Manilkara jaimiqui subsp. emarginata	14	0.56
Maytenus buxifolia	27	1.16
Metopium toxiferum	33	1.48
Mimosa bahamensis	2	0.06
Mosiera longipes	41	1.96
Myrica cerifera	8	0.32
Paspalum blodgettii	9	0.24
Paspalum setaceum var. ciliatifolium	1	0.02
Paspalum spp.	2	0.04
Passiflora pectinata	7	0.16
Passiflora suberosa	4	0.12
Pentalinon luteum	11	0.28
Phialanthus myrtilloides	3	0.1
Phyllanthus epiphyllanthus	18	0.62
Pilosocereus royenii	11	0.28
Pinus caribaea	27	1.26
Pithecellobium keyense	19	0.72
Plumeria obtusa	10	0.52

Portulaca halimoides	3	0.08
Randia aculeata	44	2.04
Reynosia septentrionalis	11	0.3
Rhachicallis americana	2	0.14
Rhynchospora floridensis	48	3.02
Sabal palmetto	16	0.42
Heterosavia bahamensis	33	1.7
Schizachyrium gracile	3	0.08
Scleria lithosperma	3	0.1
Sideroxylon americanum	2	0.04
Smilax auriculata	21	0.82
Smilax laurifolia	2	0.04
Sophora tomentosa	3	0.08
Spigelia anthelmia	0	0
Stachytarpheta fruticosa	2	0.04
Strumpfia maritima	8	0.28
Swietenia mahogani	36	1.66
Tabebuia bahamensis	48	2.24
Thouinia discolor	19	0.76
Leucothrinax morrisii	44	2.16
Tillandsia circinnata	9	0.24
Tillandsia flexuosa	3	0.08
Tillandsia utriculata	3	0.06
Turnera ulmifolia	5	0.12
Unknown sp.	6	0.14
Waltheria indica	10	0.2