Conservation and Management of the Caribbean Pine

Pinus caribaea var. bahamensis in the Turks and Caicos: Treating Scale and Burning Broadleaf

Jennifer K. Mark

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science and the Diploma of Imperial College London

September 2012
Abstract

This project investigated management techniques for conservation of the Caicos pine, *Pinus caribaea* var. *bahamensis* Morelet (Grisebach) W. H. Barrett & Golfari in the Turks and Caicos Islands UK Overseas Territory. Three current treatments for pine infestation by the invasive pine tortoise scale insect *Toumeyella parvicornis* Cockerell were assessed for their relative efficacy in reducing scale infestation of pines in Permanent Monitoring Plots established in 2010 on three pineyard islands, using datasets collected over three years. Change from the baseline scale infestation and other variables affecting pine health were analysed using linear models in R. Although no significant reduction was found for any treatment over time, raw data showed a decrease in levels of scale and an accompanying sooty mould from 2011-12.

Secondarily, prescribed fire was trialled as a management technique for controlling overgrowth of broadleaf vegetation in pineyards, and the resulting data on pine scorch and broadleaf cover pre- and post-burn analysed. Key findings included a significant reduction in broadleaf in burned plots and a significant association between high levels of scale infestation and scorch mortality. Management suggestions made in this project will contribute to ongoing conservation of the pine in the Turks and Caicos.
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ABSTRACT</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>ACKNOWLEDGEMENTS</strong></td>
<td>4</td>
</tr>
<tr>
<td><strong>1. INTRODUCTION</strong></td>
<td>5</td>
</tr>
<tr>
<td>1.1 The Caribbean hotspot</td>
<td>5</td>
</tr>
<tr>
<td>1.2 Pine rocklands</td>
<td>6</td>
</tr>
<tr>
<td>1.3 The Caicos pine – Trouble in paradise</td>
<td>7</td>
</tr>
<tr>
<td>1.4 Broadleaf control – A burning question</td>
<td>8</td>
</tr>
<tr>
<td>1.5 Aims and objectives</td>
<td>9</td>
</tr>
<tr>
<td><strong>2. BACKGROUND</strong></td>
<td>11</td>
</tr>
<tr>
<td>2.1 Study site – The Turks and Caicos Islands</td>
<td>11</td>
</tr>
<tr>
<td>2.2 Focal species</td>
<td>13</td>
</tr>
<tr>
<td>2.2.1 Pinus caribaea var. bahamensis</td>
<td>13</td>
</tr>
<tr>
<td>2.2.2 Cultural and historical importance</td>
<td>14</td>
</tr>
<tr>
<td>2.2.3 A synergy of stressors</td>
<td>15</td>
</tr>
<tr>
<td>2.3 Scale infestation of TCI pineyards</td>
<td>15</td>
</tr>
<tr>
<td>2.3.1 Alien invasive species</td>
<td>15</td>
</tr>
<tr>
<td>2.3.2 Toumeyella parvicornis</td>
<td>16</td>
</tr>
<tr>
<td>2.3.3 Parasite herbivore interactions</td>
<td>18</td>
</tr>
<tr>
<td>2.4 Pine rockland fire ecology</td>
<td>20</td>
</tr>
<tr>
<td>2.4.1 Adaptations for fire resilience</td>
<td>20</td>
</tr>
<tr>
<td>2.4.2 Broadleaf succession – a case of prescribed fire</td>
<td>21</td>
</tr>
<tr>
<td>2.4.3 Local fire use</td>
<td>23</td>
</tr>
<tr>
<td>2.5 Conservation and previous research</td>
<td>25</td>
</tr>
<tr>
<td>2.5.1 Permanent monitoring plots and scale monitoring</td>
<td>25</td>
</tr>
<tr>
<td><strong>3. METHODS</strong></td>
<td>26</td>
</tr>
<tr>
<td>3.1 Permanent monitoring plots</td>
<td>26</td>
</tr>
<tr>
<td>3.1.1 Individual pine monitoring</td>
<td>26</td>
</tr>
<tr>
<td>3.1.2 Interactions between parasitic/competitive plants and scale</td>
<td>28</td>
</tr>
<tr>
<td>3.1.3 Analysis</td>
<td>28</td>
</tr>
<tr>
<td>3.2 Prescribed fire</td>
<td>29</td>
</tr>
<tr>
<td>3.2.1 Fire plots</td>
<td>29</td>
</tr>
<tr>
<td>3.2.2 Pre-burn monitoring</td>
<td>29</td>
</tr>
<tr>
<td>3.2.3 Controlled burn</td>
<td>31</td>
</tr>
<tr>
<td>3.2.4 Post-burn monitoring</td>
<td>32</td>
</tr>
<tr>
<td>3.2.5 Analysis</td>
<td>32</td>
</tr>
<tr>
<td>3.3 Social survey</td>
<td>34</td>
</tr>
<tr>
<td>3.3.1 Survey techniques</td>
<td>35</td>
</tr>
<tr>
<td>3.3.2 Analysis</td>
<td>36</td>
</tr>
<tr>
<td><strong>4. RESULTS</strong></td>
<td>37</td>
</tr>
<tr>
<td>4.1 Permanent monitoring plots</td>
<td>37</td>
</tr>
<tr>
<td>4.1.1 Effect of plot treatment on variables affecting individual pines</td>
<td>37</td>
</tr>
<tr>
<td>4.1.2 Linear models for changes in pine health and species richness</td>
<td>39</td>
</tr>
<tr>
<td>4.1.3 Parasite herbivore interactions in PMPs</td>
<td>40</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>4.2 Controlled burn</td>
<td>43</td>
</tr>
<tr>
<td>4.2.1 Broadleaf control</td>
<td>43</td>
</tr>
<tr>
<td>4.2.2 Pine fire tolerance</td>
<td>45</td>
</tr>
<tr>
<td>4.3 Social survey</td>
<td>47</td>
</tr>
<tr>
<td>4.3.1 Key findings</td>
<td>47</td>
</tr>
<tr>
<td>4.3.2 Critique</td>
<td>48</td>
</tr>
<tr>
<td>5. DISCUSSION</td>
<td>49</td>
</tr>
<tr>
<td>5.1 Permanent monitoring plots</td>
<td>49</td>
</tr>
<tr>
<td>5.1.1 Treatments</td>
<td>49</td>
</tr>
<tr>
<td>5.1.2 Implications for management</td>
<td>51</td>
</tr>
<tr>
<td>5.1.3 Strengths and limitations</td>
<td>52</td>
</tr>
<tr>
<td>5.1.4 Suggestions for further research</td>
<td>53</td>
</tr>
<tr>
<td>5.1.5 Effect of parasitic/competitor plants on scale infestation</td>
<td>54</td>
</tr>
<tr>
<td>5.1.6 Implications for management</td>
<td>54</td>
</tr>
<tr>
<td>5.1.7 Strengths and limitations</td>
<td>56</td>
</tr>
<tr>
<td>5.1.8 Suggestions for further research</td>
<td>56</td>
</tr>
<tr>
<td>5.2 Controlled burn</td>
<td>57</td>
</tr>
<tr>
<td>5.2.1 Broadleaf control</td>
<td>57</td>
</tr>
<tr>
<td>5.2.2 Pine fire resilience</td>
<td>58</td>
</tr>
<tr>
<td>5.2.3 Implications for management</td>
<td>59</td>
</tr>
<tr>
<td>5.2.4 Strengths and limitations</td>
<td>60</td>
</tr>
<tr>
<td>5.2.5 Suggestions for further research</td>
<td>60</td>
</tr>
<tr>
<td>6. ADDITIONAL OUTPUTS</td>
<td>62</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>63</td>
</tr>
</tbody>
</table>
Acknowledgements

Firstly, I would like to thank the Whitley Wildlife Conservation Trust, Chester Zoo, the Worshipful Company of Gardeners, and the Royal Botanic Gardens, Kew for their generous contributions to the funding of this project.

The project would not have been possible without the assistance of my supervisors Colin Clubbe and Martin Hamilton. Thank you to Colin for your steady support, patience and advice. To Martin, I am grateful for your drive, motivation and field expertise, and inspirational dedication to restoring the Caicos pine. Appreciation also goes to Marcella Corcoran, for sharing her knowledge and expertise, jokes and excellent lasagne!

In TCI, I would firstly like to thank The Department for the Environment and Marine Affairs. Thanks also to Judnel Blaise for his hard work and effortless good humour, and to Bryan Naqqi Manco, an astounding source of wisdom, humour and encyclopaedic knowledge; a great mentor and a true friend.

Words of thanks go to the people of North and Middle Caicos, who patiently put up with my questions about pineyards and farming, and enthusiastically and warmly shared their experience and memories. I also very much appreciate the welcoming hospitality of The Meridian Club, Pine Cay.

Sincere thanks also to Joe O’Brien and Ben Hornsby of the USFS and David Grimm of US Eglin for their invaluable expertise, good company and practical style of teaching!

At Imperial, I would like to thank E.J Milner-Gulland for accepting me onto this course and remaining a constant font of inspiration and good advice. Likewise, my profound thanks to David Orme and Debbie Leigh for indispensable stats advice, Paul Rassell for aid deciphering R, and to Alex Hudson, fellow pineyard adventurer full of drive and determination – a truly awesome field assistant!

Finally, for their boundless support and encouragement, heartfelt thanks to my family and friends.
1. INTRODUCTION

1.1 The Caribbean Hotspot

It is widely recognised that biodiversity loss is occurring globally at an unprecedented scale and speed (Pimm et al. 1995; Mittermeier et al. 1998; Brooks et al. 2002). Ecosystems are increasingly threatened by habitat loss, spread of alien invasive species, climate change and inexorable human population growth. Up to 50% of Earth’s terrestrial area is estimated to have been occupied, converted or degraded in some way by humans (Vitousek et al. 1997). Our activities are estimated to have accelerated extinction rates by 100-1000 times the background level (Pimm et al. 1995), and this figure is expected to rise (Thomas et al. 2004). Faced with such an immense threat, and with limited conservation resources, the need to prioritise areas and ecosystems for targeted action is more urgent than ever before.

The Caribbean is one such priority. Identified as a biodiversity hotspot due to its exceptionally high levels of endemism per unit of land and equally high levels of threat (Myers et al. 2000; Shi et al. 2005), the Caribbean is amongst the major areas agreed upon as highly deserving of conservation’s limited funds. The region, which comprises the Bahamas Archipelago and the Greater and Lesser Antilles, houses 182 endemic plant genera (7000 endemic species), amounting to over half of its total flora and 2.3% of global plant species (Myers et al. 2000; Francisco-Ortega et al. 2007). This treasure-trove of unique biodiversity puts the Caribbean on a par with Madagascar in terms of endemism (Francisco-Ortega et al. 2007), and justifies its place amongst the world’s six “hottest” hotspots (Shi et al. 2005). However, as Maunder et al. (2008) note, it is not enough simply to be labelled as a priority. The endangered species and habitats of the Caribbean still require greater research attention, and urgently so.
1.2 Pine Rocklands

One such habitat is the pine rockland, or “pineyard” of the Bahamas. The ecosystem is unique to southern Florida, Cuba and seven islands of the Bahamas Archipelago (US Fish & Wildlife, 2007), three of which fall within the Turks and Caicos Islands UK Overseas Territory (TCI).

Pine rocklands are characterised by a single dominant canopy species. In Florida this is the slash pine *Pinus elliottii* Englem. subsp. *densa* (Little & K. W. Dorman) A. E. Murray; and in the Bahamas *Pinus caribaea* Morelet var. *bahamensis* (Grisebach) W. H. Barrett & Golfari, a variety of the Caribbean pine (*Pinus caribaea* Morelet) which is endemic to the Bahamas, and known locally in TCI as the “Caicos” pine. Healthy pine rocklands support a diverse understory of palms and hardwood shrubs, and a species-rich herbaceous layer (US Fish & Wildlife, 2007). The limestone bedrock and thin soils encourage rapid drainage, although high rainfall in the summer wet season causes periodic shallow flooding.

In TCI, pineyards are present on the islands of North Caicos, Middle Caicos and Pine Cay. They support a number of species endemic to the Bahamas, and provide overwintering for others such as the Near Threatened Kirtland’s Warbler, *Dendroica kirtlandii* Baird (IUCN Red List version 2012.1).

However, these pineyards are now in serious decline. Populations of *P. caribaea* var. *bahamensis*, once abundant enough to support a lucrative timber industry (Mills, 2008), are now threatened by an alien invasive scale insect, *Toumeyella parvicornis* Cockerell. Established scale populations were discovered in TCI in 2005 by Martin Hamilton of the Royal Botanic Gardens Kew (Hamilton, 2005), and since then the insect has been largely responsible for an estimated 95% die-off of mature pines (Green, 2011).
1.3 The Caicos Pine – Trouble in Paradise

As the national tree of the Turks and Caicos Islands (TCI), the Caicos pine is of major cultural as well as ecological importance, and is now a national conservation priority. A recent assessment by scientists from the Royal Botanic Gardens Kew in 2011 categorised the pine as “Vulnerable” under IUCN Red List criteria, due to its restricted geographic range and the significant level of threat the species currently faces (Hamilton, pers. comm. 2012).

The pine is threatened by invasive species; habitat destruction caused by expanding development for tourism; and climate change. Anthropogenic fire is also a substantial hazard; pineyards have in recent years been damaged by accidental spread of fires used for slash and burn agriculture, making community engagement and awareness central to ensuring good practice and long term persistence of the pine.

There are justified fears that, without conservation and management, this synergy of stressors may lead to the extirpation of the pine from TCI. Losing this dominant canopy species would have serious repercussions for the entire pineyard ecosystem (Pine Rocklands Working Group, 2010). It would also leave the pine restricted solely to four islands in the northern Bahamas where development and tourism already encroach on its range.

The Royal Botanic Gardens Kew is currently engaged in conservation, research and capacity building in TCI, as part of its UK Overseas Territories Programme. RBGK works together with in-country partners on the Caicos Pine Recovery Project (CPRP).
1.4  Broadleaf Control: A Burning Question

Biodiversity loss is a known driver of ecosystem change (Hooper et al. 2012), and this is painfully evident in TCI pineyards. With the loss of the majority of the mature trees, the Caicos pine has been largely replaced as the dominant canopy species by broadleaf shrubs and palms (Hamilton et al. 2012). Natural regeneration of pines is limited; the dense broadleaf restricts the amount of light available to low-growing plants, impacting the photosynthesis of pine seedlings and herbaceous species. It is apparent that without substantial broadleaf clearance, the pineyards will not return from this ecological “tipping point” (O’Brien, pers. comm. 2012), and open pineyard habitat will deteriorate into dense coppice, at the cost of not only the Caicos pine itself, but the diverse understory and herbaceous layers it supports (Pine Rockland Working Group, 2010).

A key objective is to determine whether or not prescribed fire, commonly used for forest management in the southern United States, would be an effective broadleaf clearance technique in scale-infested pineyards. To this end, the first controlled burn in TCI history was carried out during the course of this project’s fieldwork. Pre- and post-burn data were analysed to gauge the effects of fire on broadleaf and level of fire-resilience of infested pines. Conclusions drawn from this research will be used to inform future management.
1.5 Aims and Objectives

This project builds on the research of two previous Imperial College London MSc students, Harry Earle-Mundil (2010) and Sara Green (2011), who established permanent pineyard monitoring plots and potential scale insect treatments, and determined initial estimates of pine population size, decline and effect on the wider plant community respectively.

The aim of the project, through continued monitoring and an enhanced understanding of ecological and social factors, is to provide data and observations which will be useful in guiding and informing future management decisions to ensure long-term persistence of the Caribbean pine in the Turks and Caicos Islands. Field research was undertaken to meet the following objectives:

1. **Assess the comparative efficacy of different scale insect treatments employed in the permanent monitoring plots by providing a third year of assessments to the existing dataset established by Earle-Mundil (2010) and Green (2011).**

   - Have any of the treatments significantly affected levels of scale infestation and sooty mould cover since 2010?

   - Do the presence of the parasitic plant *Cassytha filiformis* L., and competitors *Angadenia berteroi* (A. DC.) Miers and *Jacquemontia havanensis* (Jacq.) Urb. growing on pines have an effect on scale infestation?
2. Assess the feasibility of using prescribed fire to control competitive broadleaf species in TCI pineyards, by assessing both the effectiveness of this proposed management technique and the fire-resilience of a pineyard infested by scale.

Broadleaf control:

- Did the controlled burn reduce broadleaf coverage in the fire plots?
- Was supplementary fuel-spraying necessary for reduction of broadleaf?

Pine fire-resilience:

- Was there significant fire-induced mortality amongst fire plot pines?
- Were certain age classes more susceptible?
- Does pre-fire clearance around pines affect mortality?
- Does scale infestation affect pine fire-resilience?

3. Explore the threat of anthropogenic fire to pineyards through a social survey exploring current and traditional fire-use activities, local pineyard knowledge and support for conservation work, which will pave the way for further education and awareness work within the local community.
2. BACKGROUND

2.1 Study Site – The Turks and Caicos Islands

The Turks and Caicos Islands (TCI) are a UK Overseas Territory located in the Caribbean, at the south-eastern end of the Bahamas Archipelago in the Atlantic Ocean. The territory consists of over forty low-lying islands and cays, with a total land area of approximately 499 km$^2$. A deep water channel divides the TCI archipelago in two (the Turks bank and Caicos bank), with reefs surrounding the two island groups. The islands have a dry tropical climate, with infrequent hurricanes in the summer wet season. The underlying geology is limestone with thin mineral and sandy soils, with a limited freshwater lens over saline groundwater. Despite the lack of freshwater, islands and cays support a diverse range of habitats including sea-grass beds, coastal scrub, dry tropical forest, salt marsh, mangrove and pineyard (Mills, 2008).

Figure 2.1 The Caicos Bank including Pine Cay, North Caicos and Middle Caicos (www.mapsof.net, 2012)
Popular history suggests the first humans to make landfall in the islands (around 750 AD) arrived from South America in a wooden canoe crewed by only forty voyagers (Mills, 2008); today the population numbers over 34,000 (2010 population estimate, Turks and Caicos Department of Economic Planning and Statistics, 2012). Only six islands and two cays are inhabited, including North Caicos (1500 inhabitants approx.), Middle Caicos (300 inhabitants approx.), and the privately-owned Pine Cay (less than 100 inhabitants) (Earle-Mundil, 2010).

The islands’ main sources of revenue come from tourism, provision of offshore financial services, and fishing. Although the majority of TCI’s food and other consumer products are imported, subsistence farming is still practiced on some islands, including North and Middle Caicos (Mills, 2008).
2.2 Focal Species

2.2.1 Pinus caribaea var. bahamensis

This project focuses on the conservation and management of Pinus caribaea Morelet var. bahamensis (Grisebach) W. H. Barrett & Golfari, a variety of the Caribbean pine (P. caribaea Morelet). P. caribaea var. bahamensis is endemic to only seven small islands in the Caribbean; Gran Bahama, New Providence, Andros and Abaco in the Bahamas, and North Caicos, Middle Caicos and Pine Cay in the Turks and Caicos Islands, where it is known as the “Caicos” pine. It has been hypothesised that the pine populations in the Bahamas may diverge genetically from those in the TCI (Sanchez, research ongoing). If this is the case, then conservation of TCI pineyards becomes even more important in the interests of preserving maximum genetic diversity.

Healthy mature pines can grow to 25 metres in height (Royal Botanic Gardens Kew, 2012) however the tallest recorded in the TCI are only 8 metres (Earle-Mundil, 2010; pers. obs. 2012). Mature pines produce both male and female strobili, and seed-dispersal is by wind (Royal Botanic Gardens Kew, 2012).

Figure 2.2 Healthy mature pines, Pine Cay (RBG Kew, M. Corcoran, 2012)
In the TCI, the pine grows in three geographically separate sub-populations; the pineyards of Bottle Creek/Ready Money (North Caicos), Conch Bar (Middle Caicos), and Pine Cay (see Appendix 2 for pineyard maps). As a result of this difference in location, pines in each pineyard are subject to differing environmental conditions. The underlying geology of all three islands is limestone, but pines on North and Middle Caicos grow in shallow loamy alkaline soils, while those on Pine Cay grow in sandy soils due to greater proximity to the coast (Earle-Mundil, 2010). Similarly, pines on Pine Cay are exposed to salt spray and are thought to have access to a larger underground freshwater lens, while those on North Caicos receive the greatest amount of rainfall (Hamilton, pers. comm., 2012). This variation in environmental conditions is thought to contribute significantly to the differences in health observed between islands (Hamilton et al. 2012).

2.2.2 Cultural and Historical Importance

During the 20th Century, the pineyards of the Bahamas Archipelago, including those on North and Middle Caicos, were intensively harvested for timber (Miller, 2007). The majority of pine cut in the TCI was exported, but local uses for the timber included pitch-production, boat-building, conch-hooks and torches (Mills, 2008). The Bahaman timber industry was stopped in the 1970s due to over-harvesting (Mills, 2008), although sustainable felling was this year re-started on Abaco.

The Caicos pine is now the National Tree of the TCI, due to its prominent role in the economic and cultural history of the islands. Thus, in addition to its ecological significance as a dominant keystone species, the Caicos pine should also be recognised as a valuable emblem of the ecosystem which it characterises; here is an opportunity to raise awareness and generate support for the conservation of an important ecosystem which may otherwise be overlooked by locals and tourists in favour of more charismatic wildlife.
2.2.3 A Synergy of Stressors

In addition to scale insect infestation, TCI pineyards are threatened by climate change (the low-lying topography make TCI particularly vulnerable to sea level rise), hurricane damage, habitat loss due to development, and anthropogenic fires.

These threats act synergistically; for example, healthy pines are adapted to withstand moderate hurricane damage (Miller, 2007), but if pre-weakened by scale infestation or the effects of climate change, they may be unable to weather summer storms (Hamilton, pers. comm. 2012).

2.3 Scale Infestation of TCI Pineyards

2.3.1 Alien Invasive Species

Invasive species are considered a significant threat to biodiversity (Vitousek et al. 1997, Brooks et al. 2002), and it has been suggested that they may be the greatest threat to island ecosystems (Kairo et al. 2003). Oceanic islands are more vulnerable due to their typically naive and less-competitive fauna and flora, empty niches and finite resources (Brooks et al. 2002).

The majority of biological invasions are brought about through human movement (Kairo et al. 2003) and this problem has increased globally due to the growing demand for intercontinental travel and trade, and readily accessible and affordable means of achieving it (Perrings et al. 2010).

The Caribbean has been part of a major triangular trans-Atlantic trade route since the 1500s (Mills, 2008), resulting in a history of numerous human-mediated introductions, both intentional and accidental, of non-native species (Mills, 2008).
However, the global upwards trend in introduction of invasive species (Perrings et al. 2010) is also evident here, likely as a result of the Caribbean’s booming tourism industry. A report by Kairo et al. in 2003 listed 552 non-native species. This is relatively unsurprising, as bio-security in the Caribbean is limited (Kairo et al. 2003).

The TCI are no exception, and now host such ubiquitous invasives as cedar *Casuarina equisetifolia* (Hardman, 2009) and lionfish *Pterois volitans* (GISP, 2012). The Global Invasive Species Database lists thirty exotics for TCI (GISP, 2012). However, this is likely an underestimate in light of a visit in May of this year to the pineyards by scientists from the Food and Environment Research Agency, UK and Department for the Environment and Marine Affairs, TCI. The entomological survey resulted in the collection of thirty-one species of scale insect, seven species of whitefly and two species of aphid (Hamilton et al. 2012). At least ten are thought to be new arrivals to the islands (Hamilton et al. 2012).

The TCI are now almost totally reliant on imported consumer goods (Mills, 2008) and it is evident that without significant advances in bio-security, the islands are likely to remain a prime destination for non-native species inadvertently introduced through trade. Current biosecurity is poor: importation of certain species is prohibited by the Plant Ordinance legislation (DEMA, 2012) and new collaborative measures are now in the pipeline, although focus mainly on pests of agricultural and ornamental plants (Malumphy et al. 2012).

### 2.3.2 Toumeyella parvicornis

The pine tortoise scale, *Toumeyella parvicornis* Cockerell, is an herbivorous insect pest which feeds exclusively on pines (Malumphy et al. 2012). Native to North America, it is thought to have been introduced to the TCI on live Christmas trees. The insect was first discovered affecting pines in the Conch Bar pineyard, Middle Caicos in 2005 (Hamilton, 2007). Identification of a sample sent to the UK for identification by the Food and Environment Research Agency confirmed the insect as the first recorded incidence of *T. parvicornis* in the Caribbean (Malumphy et al. 2012). Over six years the
insect has been responsible for an estimated 90% die off of pines across all three pineyard islands (Green, 2011).

The insect feeds by attaching itself to pine needles and sucking out the sap, weakening the pine and causing yellowing, canopy loss and eventual mortality. The insect also excretes sugary honeydew which coats the needles and limbs of the affected tree, as well as nearby understory plants. This honeydew provides a growth medium for a sooty mould which restricts photosynthesis and causes further dieback (Malumphy et al. 2012).

On arrival to a new area, many alien species actually fail to become established (Lockwood et al. 2006), and it has been suggested that of those which are successful, only 10-20% will have a measurable effect on their new ecosystem (Byers et al. 2002). Commonly establishment is curtailed by new climate, filled niches, lack of suitable food and new predators (Hardman, 2009). Successful invaders are in the minority. However, in the TCI a combination of favourable conditions have enabled T. parvicornis to become successfully established; here the insect appears to have no significant predators (although Hudson, 2012 investigates the possibility of predation by ladybirds and lacewings), the majority of the Caicos pines have weakened defences due to other stressors such as rising temperatures, and in the Caribbean it is no longer
subjected to the low winter temperatures which limit its lifecycle to an observed four
generations per year in its native North American range (Malumphy et al. 2012). The
number of generations achieved by the scale in sub-tropical temperatures are not yet
known, but it is expected to be substantially higher, directly contributing to the
magnitude of the infestation (Hamilton, pers. comm. 2012).

2.3.3 Parasite-Herbivore Interactions

*Cassytha filiformis* L. is an autoparasitic plant native to the Bahamas (Correll and
Correll, 1982). *C. filiformis* resembles a tangled mass of vine-like filiform tendrils, with
leaves reduced to scales. The stems do contain chlorophyll, giving the plant some
photosynthetic ability; however it is reliant on host plants for water and physical
support (Nelson, 2008). The parasite also extracts the majority of its nutrients through
the cell membranes of its host, using adhesive structures known as haustoria (Nelson,
2008). Known locally in the TCI as “love vine”, *C. filiformis* is common in pineyards
(Manco, pers. comm. 2012), where it is frequently found parasitizing pine seedlings
and saplings, amongst other woody host plants. Pines affected by *C. filiformis* exhibit
yellowing needles and die-back (pers. obs. May 2012), although on pines where there is
concurrent infestation by the scale insect, it is not always clear how much of this is the direct
result of plant parasitism.

![Figure 2.5 C. filiformis parasitizing a pine seedling, TCI 2012](image)

It is known that host-choice in herbivorous insects can be influenced by the health of a
potential host plant (Awmack and Leather, 2002). It follows that by negatively
impacting the health of their hosts, parasitic plants may reduce the attractiveness of
that host as a food source to herbivorous insects (Bass et al. 2002). It is possible
therefore that removing parasitic plants such as *C. filiformis* from pines, and thereby
improving pine health, may encourage a greater level of infestation by *T. parvicornis* (Hamilton, pers.comm., 2012).

If this is indeed the case, it is likely that removal of other, non-parasitic plants (such as *Angadenia berteroi* and *Jacquemontia havanensis*) also found growing on pines may have a similar effect. These competitors are particularly detrimental to the health of young pines, as they wind around limbs and fascicles, limiting exposure to sunlight and reducing sap flow by constricting vascular structures (pers. obs. May 2012).

Conversely, it is also possible that removing parasitic plants from pines may have the opposite effect on infestation level; it has been demonstrated that removing one stressor can reduce the impact of another, as plant parasitism can work in synergy with insect herbivory to reduce host health (Manrique *et al.* 2009), and can also attenuate the host’s natural defences against herbivore attack (Runyon *et al.* 2007). Such findings in relation to the Caicos pine would be highly informative in understanding the defences employed by the species against herbivores. Paul Green (RBGK) is currently engaged in research into whether expression of different volatile chemicals is responsible for the varying levels of scale infestation seen between individual pines (Green, pers. comm. 2012).

*C. filiformis, A. berteroi* and *J. havanensis* are routinely removed from a subset of Caicos pines as part of an experimental technique established by Earle-Mundil (2010) to control the spread of the scale insect by broadleaf clearance. The possibility of knock-on effects on insect host-selection by removing parasitic and competitive plants from pines therefore has implications for the value of broadleaf clearance as a scale insect control technique, and merits investigation.
2.4 Pine Rockland Fire Ecology

Healthy pineyards are dependent on periodic, low intensity fires for regeneration of pines and control of the broadleaf understory (Pine Rockland Working Group, 2010). Such fires occur naturally every 3-5 years and are historically caused by lightning strikes (US Fish and Wildlife, date unknown). As the dominant canopy species, pines play an important role in the fire regime of the habitat, dropping not only dead limbs but also highly flammable resinous needles which act as a major fuel source (Mitchell et al. 2009).

2.4.1 Adaptations for Fire-Resilience

Caicos pine seedlings have a fire-sensitive grass-stage lasting several years (O’Brien et al. 2008), with seedlings with a basal DBH below approximately 1 centimetre showing greatest vulnerability (Mitchell et al. 2009; O’Brien, pers. comm. 2012). Seed-banks are triggered by fire, and seedlings sprouting after fire benefit from the nutrient-rich ash, as well as greater light penetrating the fire-thinned broadleaf understory (O’Brien et al. 2008).

After the grass-stage, the pines begin to develop fire-tolerant adaptations, including self-pruning lower branches and thick, insulating outer layers of scaly bark to protect trunk heartwood (Miller, 2007). Needles are dropped after scorch (O’Brien et al. 2008), and green re-growth is typically seen within three weeks of drop (O’Brien, pers. comm. 2012).
The key question is: do pines heavily infested with scale retain this level of fire-resilience, or is their health so compromised that they cannot recover from scorch? Controlled burns have been successful for broadleaf control on Abaco and Andros (Miller, 2007) and in forests impacted by bark beetles in the United States (O’Brien, pers. comm. 2012). However, in the case of T. parvicornis, it is not yet known (O’Brien, pers. comm. 2012).

2.4.2 Broadleaf Succession: the Case for Prescribed Fire

Prescribed fire is commonly used in pine rocklands in the southern United States to replace the natural fire regime (US Fish and Wildlife, date unknown). Such management aims to reduce the risk of destructive wildfires which can occur if a break in the natural fire regime allows increased fuel build-up. In this situation, when a fire does eventually occur, it is likely to be of a high enough intensity and duration to cause significant damage to the ecosystem’s fauna and flora, including fire-tolerant species such as the Caribbean pine (Pine Rocklands Working Group, 2010).

Prescribed fires can also be necessary as a broadleaf management technique in pine rocklands where the natural fire regime has become compromised (Miller, 2007), as is the case in TCI pineyards. Population decline and most importantly loss of mature seed-producers due to scale infestation and escaped anthropogenic fire has led to lack of the resinous pine needle carpet necessary for periodic low-intensity fires (O’Brien et al. 2008). In the absence of this regular fire regime, natural broadleaf-pruning does not occur. The TCI’s evenly-aged, largely immature pine stands (Hamilton et al. 2012), left by die-off of mature pines, affect regeneration rates (Pine Rockland Working Group, 2010) and mean that in places, there is now little or no seed-bank. Therefore, pineyard areas selected for prescribed fire should be carefully assessed for regeneration potential.

Combined with the loss of a pine canopy to control understory species, the ecosystem has tipped in favour of an alternate stable state in which broadleaf species such as
*Thrinax morissi* H. Wendl, *Sabal palmetto* (Walter) Lodd. ex Schult. & Schult. f. and *Swietenia mahagoni* Jacq. dominate (Hamilton *et al.* 2012). This shift not only reduces floristic diversity in the understory, but prevents pine regeneration on the scale needed to restore the ecosystem to a pine-dominant state (O’Brien, pers. comm. 2012).

**Figure 2.8** Best remaining example of a “healthy” TCI pineyard (Pine Cay) - mature pines still dominate canopy in areas (RBG Kew, M. Hamilton, 2012)

**Figure 2.9** Broadleaf overgrowth in Conch Bar pineyard, Middle Caicos (RBG Kew, M. Hamilton, 2012)
2.4.3 Local Fire-Use

Fire-uses in the TCI include the burning of garbage (rubbish) and trash (dry leaves, plant matter) and outdoor cooking fires. However, the primary source of anthropogenic fire is clearance of scrubland for slash and burn agriculture. On North and Middle Caicos, areas of scrub or “bush” are cleared with machetes and the resulting broadleaf cuttings are burned to clear an open field. This type of farming is typically carried out in areas of bush away from settlements and close to the pineyards (Manco, pers. comm. 2012).

Figure 2.10 Maize “field” - understory bush has been cleared using slash and burn techniques. North Caicos, 2012.

Spread of unsupervised anthropogenic fires poses a significant risk to TCI pineyards, considering the amount of standing fuel-wood which has resulted from the estimated 95% die-off of mature pines (Green, 2011). In March of 2009, an escaped agricultural fire destroyed a large section of Ready Money pineyard on North Caicos (Hamilton et al. 2012). Although the fire occurred in the dry season and there were strong winds (Manco, pers. comm. 2012), it is likely that mortality from scale insect infestation had increased the amount of dead pine stumps and standing snags, fuelling a higher intensity fire which caused greater destruction.
Lighting of any outdoor fires is illegal in TCI, although this prohibition is largely disregarded; burning is the main way to dispose of rubbish in the islands (pers. obs., 2012), and slash and burn agriculture is practised by a high proportion of elderly people on Middle Caicos. There is little enforcement available, and in the small community, nepotism is difficult to avoid (Manco, pers. comm. 2012).

An additional problem stems from the fact that a significant proportion of the non-Belongs community are in the TCI illegally. For this reason, many people are reluctant to talk about fire-use, and may venture further into the bush (nearer to the pineyards) to light their fires (Manco, pers. comm. 2012).

Even if total enforcement were possible, it is not the answer to reducing agricultural fires. Many practitioners on Middle Caicos are reliant on slash and burn for subsistence (Manco, pers. comm. 2012). A better way to address fire-use practices which pose a risk to pineyards is, where possible, through community engagement and awareness; especially by first tackling topics which are less sensitive, such as taking precautions when burning trash or garbage in yards. But education and awareness campaigns can risk being ill-informed or patronising unless the issues have first been investigated thoroughly. Therefore common practices must first be fully explored and understood.
2.5 Conservation and Previous Research

2.5.1 Permanent Monitoring Plots and Scale Monitoring

Permanent monitoring plots (PMPs) were established in 2010 in pineyards on North Caicos, Middle Caicos and Pine Cay by Harry Earle-Mundil in association with CPRP and RBGK. Three 10 metre by 10 metre plots on each island; each plot received one of two treatments for the invasive scale insect, or no treatment at all (control plot). Each pine within the plots was given a unique numbered ID tag for use in future health assessments. Plots 3, 6, 9 receive broadleaf clearance in a 0.5 metre radius around each pine; plots 1, 4, 7 receive broadleaf clearance and a non-insecticide soap spray; plots 2, 5, 8 receive no treatment or clearance and were designated control plots. Plots are maintained by CPRP staff and treatments applied biannually (Earle-Mundil, 2010). Baseline levels of scale, sooty mould and other pine variables (see Table 3.1) were recorded by Earle-Mundil (2010).

Re-assessment of PMPs by Sara Green in 2011 showed an increase in scale and sooty mould, with the least effective treatment appearing to be broadleaf clearance, and the most effective being clearance with soap spray (Green, 2011).
3. METHODS

A handheld PDA (with integrated GPS) running ArcPad ESRI Version 10 was used for all data recording in the field, and data were subsequently cleaned using BRAHMS (Botanical Records and Herbarium Management System) and Microsoft Office Excel 2007. Correll and Correll’s *Flora of the Bahama Archipelago* (1982) was consulted for species identifications made by J. Mark and A. Hudson.

3.1 Permanent Monitoring Plots

To determine whether the treatments employed by the CPRP to combat the invasive scale insect vary in their effectiveness at reducing levels of scale and sooty mould, a third year of assessments were carried out on the Permanent Monitoring Plots established by Earle-Mundil in 2010. Assessments undertaken this year will supplement the dataset compiled by Earle-Mundil (2010) and Green (2011). Such continued monitoring is vital if the most effective treatment is to be selected for wider pineyard use. Conversely, if no significant reduction in infestation is found, then it may be prudent to conclude that the original treatments are not suitable, and alternatives should be investigated.

To ensure comparability of the three years of PMP data, consistency must be maintained. Therefore, data-collection adhered to the original methods for assessments of individual pines (Table 3.1) outlined by Earle-Mundil (2010) and repeated by Green (2011).

In addition, a vegetation assessment (producing a full species list of plot flora) was undertaken for each PMP, with the identification expertise of Bryan Naqqi Manco, DEMA.
### 3.1.1 Individual Pine Monitoring

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of Pine Tortoise Scale Infestation</td>
<td>The level of scale infestation on the pine tree. Measured on a scale of 0 – 5; 0 being scale-free; 5 being totally infested.</td>
</tr>
<tr>
<td>Level of Canopy Damage</td>
<td>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.</td>
</tr>
<tr>
<td>Sooty Mould Coverage</td>
<td>The coverage of sooty mould, recorded as a percentage of the total leaf area covered by mould. Estimated by eye to the nearest 5%.</td>
</tr>
<tr>
<td>Pine Height</td>
<td>The height of the pine tree in metres.</td>
</tr>
<tr>
<td>Pine DBH</td>
<td>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 pine was measured instead.</td>
</tr>
</tbody>
</table>

DBH tape was used to measure tree and sapling DBH at 1.27m, and electronic callipers were used to measure basal diameter of seedlings and short saplings. A clinometer was used to record heights of pines which were too tall to be recorded using measuring tape.

![Figure 3.1 Measuring basal diameter of a pine seedling using callipers, Pine Cay. (RBG Kew, M. Corcoran, 2012)](image)

A DNA sample (needles preserved in silica gel) for processing at RBGK was taken from all new seedlings found to have sprouted since the last assessments in July 2011 (with the exception of one, which was recorded as requiring a sample), and a metal tag with unique identification number was attached to a rock at the base of each.
3.1.3 Interactions between Parasitic/Competitor Plants and Scale

To better assess pine health and investigate whether the presence of parasitic and competitor plants on pines has an effect on scale infestation level, additional recordings were made for each pine noting the presence/absence of yellowing needles and a species-level identification of any plant found growing on that pine.

3.1.4 Analysis

Linear models in R (CRAN) were used to compare this year’s individual pine assessment and plot species richness data to those collected by Earle-Mundil (2010) and Green (2011). Mean averages were calculated in Excel per plot for each response variable, to account for pseudo-replication within each PMP. “Island” was incorporated as a fixed effect in each linear model.

The most appropriate model for each response variable was found by backwards stepwise deletion of insignificant terms from the maximal model, then comparison of the deviance of each reduced model with the previous one using ANOVA. Any terms whose deletion resulted in a significant increase in deviance were re-added to the model. While a minimal adequate model should contain only significant terms (Crawley, 2007), it is also important to ensure that the model “fits” the data as well as possible (Crawley, 2007; Orme, pers. comm., 2012). To this end, diagnostic plots were generated in R for each model to give an idea of relative fit. Therefore in some instances terms were retained, despite their deletion causing no significant increase in deviance, because diagnostic plots illustrated that their inclusion improved the fit of the model to the data.

Data collected this year for presence/absence of *C. filiformis*, *A. bertero* and *J. havanensis* on PMP pines were analysed using Chi-square and Fisher’s Exact Test.
3.2 Prescribed Fire

To investigate the feasibility and gauge the likely pros and cons of prescribed fire as a broadleaf control technique in TCI pineyards, a trial controlled burn was carried out on 9th May 2012 at Conch Bar pineyard on Middle Caicos. Pre and post-burn monitoring was undertaken to assess the effects of the fire on broadleaf cover and the pines themselves.

3.2.1 Fire Plots

In November 2011, staff from RBGK and the CPRP established two triangular fire plots, each covering approximately 1 acre of pineyard, at Conch Bar, Middle Caicos. Plot 1 was established using the King’s Road as one side of the triangle. Plot 2 was further into the pineyard away from the road, adjacent to the PMPs.

Broadleaf vegetation was manually cleared to a minimum radius of 1 metre around each pine to minimise combustion mortality, and the resulting broadleaf cuttings were spread over the bare limestone areas of each plot to increase fuel continuity in the absence of pine needles. Fuel spread was more even in plot 1 than in plot 2, where the majority was piled into large “jackpots” (fuel piles).

On 8th May 2012, a quarter-acre control plot (no mechanical clearance or fuel manipulation) was established close to the existing fire plots, to assess whether the intensive pre-burn management employed in plots 1 and 2 will be a necessary requirement before all future controlled burns. All three plots were surrounded by firebreaks to prevent fire spread into the wider pineyard. The plots were delineated with corner posts and mapped using the minimum data points function in ArcPad.

3.2.2 Pre-Burn Monitoring

In both plots 1 and 2, a 50 metre transect was established running roughly north-south from base to apex of each triangle. The first 10 metres at the base and the first 20 metres at the apex were left as buffers, as the fire would burn most intensely in the middle of the plots and less so at the edges, thus having variable effect on plot vegetation (O’Brien, pers. comm. May 2012). 200m² sampling plots were established
at 5 points along each transect, spaced 10 metres apart. A metal ID tag was attached to rock at the centre of each, and these points mapped using ArcPad. This process was repeated in the control plot, although the sampling points were established in a cross rather than a linear transect, due to the size and shape of this plot.

Pine stand density was recorded at each sampling point using a modified version of the point-centred quarter (PCQ) method (Cottam and Curtis, 1956). Each 200m$^2$ sampling plot was divided into quarters along cardinal compass points, and the distance from plot centre to the nearest pine seedling, sapling, and tree was measured with tape. Height (metres) and DBH (centimetres), or basal diameter for pines less than 1.27m tall, were recorded for each PCQ pine, and whether said pine was living or dead. Fuel and broadleaf cover were also assessed, following guidelines in Table 3.2, and a full species list compiled at each point.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of Canopy</td>
<td>The average height of vegetation in the PCQ plot in metres. Estimated by eye to the nearest 5%.</td>
</tr>
<tr>
<td>Canopy Density</td>
<td>The percentage canopy cover of vegetation in the PCQ plot. Estimated by eye to the nearest 5%.</td>
</tr>
<tr>
<td>Ground Cover</td>
<td>The percentage of ground covered by vegetation. Estimated by eye to the nearest 5%.</td>
</tr>
<tr>
<td>Level of Pine Tortoise Scale Infestation</td>
<td>The average level of scale infection in the PCQ plot. Measured on a scale of 0-5; 0 being scale-free; 5 being scale covering every pine tree in the PMP.</td>
</tr>
<tr>
<td>Level of Canopy Damage</td>
<td>The average level of canopy loss of live pines in the PCQ plot. Measured on a scale of 0-5; 0 being no canopy loss; 5 being total canopy loss.</td>
</tr>
<tr>
<td>Sooty Mould Coverage</td>
<td>The coverage of sooty mould, recorded as a percentage of the total needle area covered by mould. Estimated by eye to the nearest 5%.</td>
</tr>
<tr>
<td>Fuel Level</td>
<td>Overall fuel level in PCQ plot, estimated by eye to nearest 5%.</td>
</tr>
<tr>
<td>Fuel Types</td>
<td>All fuel types present in PCQ plot</td>
</tr>
<tr>
<td>Plot Height</td>
<td>Height (m) of the tallest plant in the central 1 metre squared of PCQ plot.</td>
</tr>
<tr>
<td>Plot Litter</td>
<td>Depth (cm) of ground litter in the central 1m$^2$ of PCQ plot</td>
</tr>
<tr>
<td>Plot Species Cover</td>
<td>Relative cover of each species found growing within the central 1m$^2$ estimated by eye on a 1-5 scale. Criteria for “plot species” = any part of that plant extends into the central 1m$^2$.</td>
</tr>
</tbody>
</table>
In addition, copper tags were attached to one sapling and one seedling per plot, to monitor change in level of scorch over time, and any change in levels of scale infestation (A. Hudson, 2012). Tagged trees were assessed using guidelines outlined in Table 3.1, with the addition of scorch level (measured by eye to the nearest 5%).

3.2.3 Controlled Burn

On 9\textsuperscript{th} May 2012, the first controlled burn in the TCI was carried out, following US Forest Service (USFS) protocol, by Joe O’Brien (USFS), Ben Hornsby (USFS) and David Grimm (Eglin Air Force Base, USA), mentoring CPRP staff. Drip torches were used for ignition and backpack sprayers to extinguish any burning debris which crossed the firebreaks. All three fire plots were ignited under the same weather conditions. The day before the burn, fire plots were assessed for suitability by J. O’Brien, B. Hornsby and D. Grimm, and a combustion test was carried out to ensure available fuel would burn readily. The site was revisited post-fire (10/05/12 and 13/05/12) with backpack sprayers to extinguish any still-smouldering patches.

![Figure 3.2 Using a drip torch to light broadleaf, 2012](image1)

![Figure 3.3 Controlled burn, Conch Bar pineyard, Middle Caicos (J. O’Brien, 2012)](image2)
3.2.4 Post-Burn Monitoring

Post-fire (10/05/12) the copper tags were removed and replaced with corresponding unique ID tags attached to rocks. It was decided (J. Mark and A. Hudson) that additional fire plot saplings and seedlings be tagged, giving a larger sample from which to investigate changing levels of scorch and mortality or regeneration over time. Forty-six additional pines were tagged, including the only six trees present in the fire plots (see Table 3.3) on the 13th and 15th May 2012.

<table>
<thead>
<tr>
<th>Fire Plot</th>
<th>Seedling</th>
<th>Sapling</th>
<th>Tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (clearance &amp; fuel manipulation)</td>
<td>8</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2 (clearance &amp; fuel manipulation)</td>
<td>10</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>3 (control)</td>
<td>5</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

All PCQ plots and tagged pines were re-assessed twice post-fire, with data-collection consistent with pre-fire methods; exceptions were number of data-collectors, depending on availability; and the addition of crossed sticks laid over the tagged rock at the centre of each PCQ aligned to N, S, E, W compass points (rather than one person standing at each compass point), to allow a reduced number of collectors to complete each assessment in the time available. The first post-fire assessment (29-30/05/12) was undertaken by J. Mark, B. N. Manco (DEMA), M. Corcoran (RBGK) and A. Hudson (Imperial College); the second by J. Mark and A. Hudson (01-03/07/12).

3.2.5 Analysis

Values were calculated in Excel for the mean average per transect of the following variables: fuel cover; ground cover; species cover per central metre squared; and species richness. The means per transect for each of the three fire plot assessments (pre-burn, first post-burn and second post-burn) were described graphically using R, to gauge change in broadleaf cover and degree of fuel consumption for each fire plot.
Although the PCQ method was used for each sampling point along the fire plot transects, the resulting pine data were not used to find stand density. This was because of several limitations in the methodology (see Discussion) which resulted in decreased reliability of some of the data.

These data were instead used to find the change over time in mean distance from centre of the plot to the nearest sapling and seedling. Values for mean change in distance per transect were plotted and assessed graphically for an indication of change in broadleaf cover.

To investigate whether pines of different age-classes are more vulnerable to fire damage than others, and to assess whether clearance around pines significantly decreases the incidence of terminal scorching, data for the tagged fire plot pines were displayed graphically to show scorch-mortality by plot and by habit (age-class). Fisher’s Exact Test was then used to look for associations between scorch-mortality and habit, and between scorch-mortality and plot treatment (pre-burn management or control).

To assess the effect of the scale insect on pine fire-resilience, the mean pre-fire scale infestation levels of tagged saplings which survived were compared to those of saplings which died as a result of scorch, using Wilcoxon-Mann-Whitney tests in R, and the same analysis carried out for tagged seedlings. Data for tagged trees were excluded from this analysis, as out of six trees tagged, only one died as a result of scorch, giving too small a sample size for drawing conclusions of any reliability. Additionally, the change in percentage scorch of tagged pines over time was graphed in R to describe regeneration.
3.3 Social Survey

Pineyard-use has undergone dramatic changes over the last few decades, from intensive use for timber, to decimation by the invasive pine tortoise scale insect, to research and management by the CPRP and RBGK. Successful conservation almost always involves social considerations and the involvement of local people; given the considerable cultural and historical importance of the Caicos pine and bearing in mind the catastrophic effects of unsupervised fires, this is clearly doubly important in the TCI. To this end, a social survey was carried out on North and Middle Caicos to investigate:

- Common fire-use activities which may put pineyards at risk: slash and burn agriculture; burning trash or garbage; charcoal-making; outdoor cooking fires

- Local awareness of past pineyard fires and understanding of the fire ecology of the Caicos pine (this will guide future education and awareness campaigns if controlled burns become a common pineyard management technique)

- Cultural and historical importance of pineyards in the TCI

- Local awareness of the work of the CPRP, and opinions on pineyard conservation

- The most effective ways to inform local people about current pineyard conservation in such a way as to ensure inclusion of all communities on North and Middle Caicos
3.3.1 Survey Techniques

The survey originally took the form of a paper questionnaire, which was trialled at a community meeting at Conch Bar, Middle Caicos (01/05/12). Following this informal pilot, the questionnaire was reviewed and alterations were made to the wording (after discussion with Bryan Naqqi Manco, DECR). The questionnaire was then re-formatted as an Excel spreadsheet (Appendix 1) for ease of recording.

![Figure 3.4 Pilot study at Conch Bar community meeting (RBG Kew, M. Corcoran, 2012)](image)

The main survey was conducted by J. Mark, accompanied by B. N. Manco, (3rd-6th July 2012) at Conch Bar and Bambarra on Middle Caicos and Bottle Creek and Kew Village on North Caicos. Eleven questionnaires were carried out (three of which were jointly answered by couples). An attempt was made to cover a representative sample of responders in terms of age, gender and nationality (main nationalities on North and Middle Caicos are TCI Belonger and Haitian).

A laptop was used to record answers, and the majority of the survey took the form of informal interviews rather than rigidly adhering to pre-written questions. Interviews were carried out at responders’ houses / workplaces. J. Mark was introduced by B. N. Manco as “a student studying the pineyards, interested in finding out about local farming practices and what people know about the pineyards”. After each interview, responders were offered a potted Swietenia mahagoni sapling from the Kew Government nursery for giving their time.
3.3.2 Analysis

Due to the small sample size, a qualitative critical review of survey techniques was more appropriate than statistical analysis. A series of recommendations was formulated to inform future surveys and education/awareness work by the CPRP and RBGK.
4. RESULTS

4.1 Permanent Monitoring Plots

4.1.1 Effect of Plot Treatment on Variables Affecting Individual Pines

Figure 4.1 Relative change in means for six environmental and physical variables affecting individual pines in Permanent Monitoring Plots receiving different treatments from 2010-2012. "B" = broadleaf clearance, "BS" = broadleaf clearance & soap spray, and "C" = control.
Data from individual pine assessments from 2010-12 were used to find mean average of each response variable per plot treatment type. Fig. 4.1 describes the resulting changes over time.

Following a treatment-wide increase in 2011, mean scale infestation has decreased in both broadleaf clearance and clearance & soap-spray plots, with steepest fluctuation for pines receiving clearance-only. Levels in control plots have continued to rise, and now constitute highest recorded level for any treatment type.

Mean mould coverage decreased across all treatments, but most steeply in broadleaf clearance plots, following last year’s substantial increase from baseline.

After a dramatic decrease across all treatments in 2011, mean levels of canopy loss have now risen above baseline in broadleaf clearance & soap spray plots, but remain below baseline in control and clearance-only plots. Averages across treatments now converge around the 1.4 level.

Assessments in 2011 showed a slight increase in mean species richness across all treatments, with the greatest increase in control plots. This year’s data show a statistically significant increase (Table 4.1) that is substantial in control plots and minimal for other treatments.

Mean height and mortality have continued to increase steadily across all treatments since baseline establishment in 2010, with highest mean mortality occurring in clearance-only plots following both treatment years. Average height continues to be greatest in clearance and soap-spray plots, and lowest in clearance-only plots.
4.1.1 Linear Models for Changes in Pine Health and Species Richness

Table 4.1 Results of linear models in R, showing the significance of plot treatment type and island on six variables affecting pines in the Permanent Monitoring Plots from 2010-2012. Values for insignificant (NS) terms were recorded at time of deletion from model. Degrees of freedom (d.f.) illustrate order of term-deletion.

<table>
<thead>
<tr>
<th>Response Variable</th>
<th>Adjusted $R^2$ of model</th>
<th>Term</th>
<th>d.f.</th>
<th>F-value</th>
<th>Pr(&gt;F)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Scale Infestation Level</td>
<td>0.319</td>
<td>Island</td>
<td>2</td>
<td>7.352</td>
<td>0.0122</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Treatment</td>
<td>2</td>
<td>6.850</td>
<td>0.0151</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Year</td>
<td>3</td>
<td>1.776</td>
<td>0.1956</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Treatment:Year</td>
<td>4</td>
<td>0.526</td>
<td>0.4760</td>
<td>NS</td>
</tr>
<tr>
<td>Mean Mould Coverage</td>
<td>0.550</td>
<td>Island</td>
<td>2</td>
<td>32.895</td>
<td>6.55e-06</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Treatment</td>
<td>2</td>
<td>0.858</td>
<td>0.3640</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Year</td>
<td>3</td>
<td>0.613</td>
<td>0.4410</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Treatment:Year</td>
<td>4</td>
<td>0.513</td>
<td>0.4810</td>
<td>NS</td>
</tr>
<tr>
<td>Mean Canopy Loss</td>
<td>0.377</td>
<td>Island</td>
<td>2</td>
<td>13.895</td>
<td>0.0011</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Treatment</td>
<td>3</td>
<td>0.027</td>
<td>0.8713</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Year</td>
<td>2</td>
<td>3.821</td>
<td>0.0624</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Treatment:Year</td>
<td>4</td>
<td>0.075</td>
<td>0.7868</td>
<td>NS</td>
</tr>
<tr>
<td>Mean Height</td>
<td>0.153</td>
<td>Island</td>
<td>2</td>
<td>4.406</td>
<td>0.0465</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Treatment</td>
<td>2</td>
<td>2.292</td>
<td>0.1431</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Year</td>
<td>3</td>
<td>1.364</td>
<td>0.2548</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Treatment:Year</td>
<td>4</td>
<td>0.033</td>
<td>0.8575</td>
<td>NS</td>
</tr>
<tr>
<td>Pine Mortality</td>
<td>0.470</td>
<td>Island</td>
<td>2</td>
<td>2.700</td>
<td>0.1130</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Treatment</td>
<td>3</td>
<td>0.745</td>
<td>0.3970</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Year</td>
<td>2</td>
<td>22.320</td>
<td>8.37e-05</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Treatment:Year</td>
<td>4</td>
<td>0.183</td>
<td>0.6727</td>
<td>NS</td>
</tr>
<tr>
<td>Plot Species Richness</td>
<td>0.288</td>
<td>Island</td>
<td>2</td>
<td>9.025</td>
<td>0.0061</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Treatment</td>
<td>3</td>
<td>0.127</td>
<td>0.7251</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Year</td>
<td>2</td>
<td>3.477</td>
<td>0.0745</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Treatment:Year</td>
<td>4</td>
<td>0.992</td>
<td>0.3299</td>
<td>NS</td>
</tr>
</tbody>
</table>

Despite the changes illustrated in Fig. 4.1, linear models found no significant change in means of ecological variables as a result of treatment over time (Treatment:Year). “Island” was a significant factor in changes seen for all variables except pine mortality, and significance was greatest for decrease in mean mould coverage (<0.001). “Year” was significant for three variables; mean canopy loss (<0.1), mortality (<0.001) and plot species richness (<0.1). Interestingly, “Treatment” was a significant factor for changes in mean level of scale infestation (<0.05), although the interaction between Treatment and Year was not significant.
4.1.3 Parasite-Herbivore Interactions in PMPs

For the purposes of this analysis, “parasitic/competitor plant” refers to Cassytha filiformis, Angadenia berteroi and Jacquemontia havanensis, all of which were observed growing on PMP pines.

A chi-square test for differences carried out on the data presented in Fig. 4.2 found a significant difference between the observed and expected frequencies ($\chi^2 = 17.90, p < 0.01$); the significant difference between expected (15.5; 15.5; 15.5) and observed (21; 24; 20) frequencies shows that the majority of pines with parasitic/competitor plants also have substantial scale infestation (level 3, 4 or 5).
Out of 428 pines recorded, 93 had parasitic or competitor plants growing on them (Fig. 4.3). A chi-square test carried out on these data found a significant association between plot treatment and incidence of parasitic/competitive plants. A significantly greater proportion of the pines with parasitic/competitive plants growing on them were found in control plots ($\chi^2 = 22.79, p < 0.001$); of the 187 pines growing in control plots, a significantly higher frequency 60 (32%) had a parasitic/competitive plant growing on them.

This is significantly higher than the expected frequency (40.63). In comparison, only 11 (9.8%) of pines in clearance & soap spray plots, and 22 (17%) of pines in clearance-only plots were found to have a parasitic/competitive plant. These observed frequencies are significantly lower than expected (24.34 and 28.03).
Table 4.2 Frequency of PMP pines with and without a parasitic/competitor plant and frequency of the same with yellowing needles (expected values in parentheses). 2012 dataset

<table>
<thead>
<tr>
<th>Yellowing</th>
<th>Parasitic Plant</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Present</td>
<td>Absent</td>
</tr>
<tr>
<td>Present</td>
<td>34</td>
<td>132</td>
</tr>
<tr>
<td></td>
<td>(36.07)</td>
<td>(129.92)</td>
</tr>
<tr>
<td>Absent</td>
<td>59</td>
<td>203</td>
</tr>
<tr>
<td></td>
<td>(56.93)</td>
<td>(205.07)</td>
</tr>
<tr>
<td>Total</td>
<td>93</td>
<td>335</td>
</tr>
</tbody>
</table>

A chi-square test carried out on the data presented in Table 4.2 found no significant association between presence/absence of a parasitic plant and presence/absence of yellowing on the same pine ($\chi^2 = 0.248$).
4.2 Controlled Burn

4.2.1 Broadleaf Control

The controlled burn caused a decrease in all variables presented in Fig. 4.4. Fire plot 1 showed the steepest decline in canopy density, followed by the control, while plot 2 saw only minimal decrease. By the first post-fire assessment, mean ground cover had decreased markedly for all plots, with values converging around the 20% level. Pre-fire species richness was highest in plot 1 and lowest in plot 2, but all plots displayed similar degrees of decline in the first post-fire assessment. Levels of all variables...
increased substantially by the second post-fire assessment, with the exception of fuel level. Mean ground cover returned to pre-fire levels in plots 1 and 3, and species richness had risen above original levels across all plots by the second post-fire assessment.

Figure 4.5 Change in mean distance from plot centre of Point Centre Quarter plots to nearest pine seedling and sapling, pre- and post-controlled burn.

Data from PCQ plots displayed in Fig 4.5 shows that, in the control plot, fire brought about minimal change in distance from plot centre to nearest sapling. Distance had increased slightly by the second post-fire assessment in plot 1, and increased in plot 2 immediately following the burn, then decreasing to just below original levels.

In contrast, distances to the nearest seedling increased by almost three metres in plot 1 by the first assessment, and remained at around six metres. Mean distance in plot 2 fell by approximately half a metre post-fire, increasing again to original distance by the second assessment. The control plot showed only slight decrease over time.
4.2.2 Pine Fire-Tolerance

The majority of tagged pines which were scorched dropped their needles after approximately six weeks post-fire, and were showing green re-growth by second post-fire assessments. Figures 4.6 and 4.7 illustrate regeneration on a single pine.

![Figure 4.6 Scorched pine with some re-growth, second post-fire assessment](image1)

![Figure 4.7 Same pine with greater progression of re-growth, third post-fire assessment](image2)

However, some scorch-mortality did occur; 21.9% of tagged fire plot saplings and 34.2% of tagged seedlings died as a result of scorch (i.e. were alive in first-post fire assessments, hence mortality was not caused by combustion).

Results of two Wilcoxon-Mann-Whitney tests in R to look for significant difference between initial (pre- or immediately post-fire depending on time of tagging) scale infestation levels of tagged saplings which were scorch-tolerant, and those which died from scorch. This was repeated for tagged seedlings. Both tests showed significant difference in initial infestation levels:

Seedlings: \( W = 275, p\text{-value} = 0.1942 \)

Saplings: \( W = 149, p\text{-value} = 0.3679 \)
A Fisher’s Exact Test to look for association between pine age-class and scorch-mortality found no evidence of a significant association ($p$-value = 0.1717).

This result was unexpected, considering fire-tolerance in pines increases with age (Mitchell et al. 2009); perhaps the majority of the saplings recorded were small, and the majority of the seedlings recorded were large, so the two age classes were similar in size?

Consequently, a Wilcoxon Rank Sum Test was used to compare mean basal DBH of the pines in question, (omitting 5 trees and 3 saplings which were sufficiently tall for standard DBH measurement). However, the test results showed significant difference between basal DBH of the age-classes ($W=51.5$, $p$-value = $1.72e^{-10}$).

Using data displayed in Fig. 4.8, a Chi-square test for association between plot and scorch-mortality found no significance ($\chi^2 = 2.1603$).
4.3 Social Survey

Social surveys, particularly those asking potentially sensitive questions, cannot be carried out successfully without some degree of integration into the study community. For this reason, small, close-knit communities such as North and Middle Caicos are not easily surveyed. However, with the help of B. N. Manco, some interesting and useful knowledge was obtained, including local views on pineyards, fire and the Caicos pine, fire-use, traditional farming and conservation.

4.3.1 Key Findings:

The overwhelming majority of respondents who practise slash and burn agriculture were in the <60 age range, and traditional methods of field clearance: using machetes to cut bush, burning the dry cuttings and raking the ground flat. Fires were mainly reported as taking place in the dry season, no extra fuel or accelerants were used, and it was considered standard practice to cut firebreaks, although not to constantly supervise fires, “unless it is very windy”.

There was a general lack of awareness regarding past pineyard fires, although both man-made fires and lightning received equal weight as fire threats to pineyards.

Amongst the older respondents who had worked in the pineyards during the days of the timber industry, there was a mixed awareness of pine fire-tolerance, and was understandably based on personal experiences of pineyard fires, or local lore, for example: “Grandfather always told me dig a hole for cooking fires, when we worked in the pineyards, because you must avoid burning the pines”

Views on conservation amongst older respondents were predominantly skewed towards restoring use-value of the pines for timber; younger respondents also mentioned the importance of the pines for future generations, and that the Caicos pine is special to TCI, and should not be lost.

Popular ways for the CPRP to reach more people were: via local TV; newspaper (although supply issues on Middle Caicos may reduce range); community meetings;
school visits; and radio. Several Haitian respondents were enthusiastic about the translation of CPRP news into Creole.

4.3.2 Critique

Time restrictions, small sample size and necessity of accompaniment by a member of the community (B. N. Manco) highlight the fact that this survey really merits its own research project. Ideally, the surveyor would live in the local community for several months to integrate before beginning a survey.

However, the survey can be viewed as a valuable “testing of the waters” from which some recommendations for future education and awareness work can be made:

- It does not appear that traditional slash and burn agriculture as practised by the older generation constitutes as great a risk as previously thought (cutting of firebreaks, wariness around pines, etcetera). However, catastrophic pineyard fires have occurred in the past, so it may be that these safety precautions are not practised by younger people.

- There is considerable scope for an educational documentary to be made regarding the pineyard history, ecology and conservation. It would be valuable to involve older people who have memories of working in the pineyards, giving an important socio-cultural context.

- Translation of any CPRP news into Creole for broadcast on local radio would ensure wider engagement of a large proportion of the TCI community. J. Blaise and B. N. Manco of the CPRP are well-placed to do this.

- Should controlled burns and scale treatment prove effective in restoring pine health in areas of Conch Bar pineyard, there is also opportunity for visits by schoolchildren and tourists to an otherwise largely overlooked habitat.

- There is an interest in the Caicos pine; respondents predominantly wanted to see it conserved for posterity.
5. DISCUSSION

5.1 Permanent Monitoring Plots

5.1.1 Treatments

As the second year of assessment since baselines were established, it was hoped that analysis of data from PMP pines would find significant interaction between treatment and year, confirming that at least one plot treatment had had a significant effect on infestation since plot establishment. Disappointingly, analysis using linear models found no significant interaction, answering the research question “have any of the treatments significantly affected levels of scale infestation and sooty mould cover since 2010?” in the negative. However, Fig. 4.1 describes trends which, while not all statistically significant, should not be disregarded:

The treatment-wide increase in mean height and mortality since baseline assessments is unsurprising, as is the statistical significance of the increased mortality, considering the nature of these two variables and the fact that only living pines were included in baseline assessments (Earle-Mundil, 2010). Broadleaf clearance plots showed greatest increase in mortality, and these plots also showed the greatest increase in mean levels of sooty mould and scale infestation in 2011, so it is likely that the majority of the broadleaf clearance pines which died since last year’s assessments were those with the highest levels of scale and mould in 2011.

This theory is reinforced by the dramatic decrease in scale and mould in broadleaf plots from 2011-12. Initially it would appear that broadleaf clearance has been most effective at reducing infestation and mould coverage. However, when viewed together with mortality it becomes apparent that the reduction is probably due to death of the most heavily infested pines which would have been the greatest contributors to the high infestation and mould levels for broadleaf plots in 2011, and does not truly represent an increase in the treatment’s mould-reduction efficacy.
If this is the case, it could be inferred that clearance & soap spray plots showed the greatest “legitimate” decrease in mould. However, mortality also increased in these plots since 2011, albeit to a lesser extent. The similar trends in mortality and mould seen in control plots suggest that none of the treatments has actually had a significant effect on mould, and the decreases are largely due to mortality of those pines which had heavy coverage in 2011.

Mortality seems to have similarly affected mean scale levels, especially considering 2011 assessments saw an increase from baseline levels across all treatment types. Again, this year’s decrease was greater in clearance-only plots than in those receiving clearance and soap spray. However, mean infestation continued to increase in control plots, so it cannot be asserted that decreases recorded for non-control treatments were simply due to the death of heavily-infested individuals. This suggests that clearance alone – and in combination with soap spray – has at least some efficacy in scale-reduction.

Although scale and mould have continued to be lowest in plots receiving both clearance and soap spray, it is noted that pines in these plots had the lowest baseline levels, as well as the greatest initial mean height, so were possibly healthier originally and thus better able to resist infestation.

This year’s treatment-wide increase in canopy loss is surprising. Considering the dramatic dip in 2011 and this year’s subsequent rise to near-baseline levels, inconsistency in defining “canopy loss” seems likely. Although assessments each year followed protocol outlined by Earle-Mundil (2010), there is no fixed definition, and it appears Mark and Earle-Mundil used similar definitions, while Green’s differed, producing the otherwise unlikely fluctuation.

In terms of species richness, it is to be expected that any rise would be greatest in plots without clearance. But this does not explain the increase itself. Both assessments were carried out in May (2011-12), so it is unlikely that there was any floodwater impeding species-counts last year. It is more likely that this year’s “extra” species were herbaceous plants which have grown since last year and were hence easier to spot.
The significance of “Island” for changes in all but one variable (Table 4.1) highlights the environmental differences between pineyards on Pine Cay, North and Middle, and suggests that these differences are having a considerable effect of relative pine health.

5.1.2 Implications for Management

Although the changes from baseline mean infestation and mean mould coverage were not found to be statistically significant, the decrease in mean scale and mean mould since 2011 for both non-control treatments and continued rise in the absence of treatment (Fig. 4.1) suggest that treatment is having some effect in reducing scale infestation. Since it seems likely that some of the decrease in mean mould and mean scale for clearance-only plots results from pine mortality since last year, and considering these plots have had the highest mortality since baseline establishment, it appears that a combination of clearance and soap-spray has been most effective at controlling scale.

However, without statistical proof, this cannot be confirmed. A further year of monitoring is therefore recommended, before embarking on widespread application of this treatment in pineyards. It is important to realise that this treatment is the most demanding in terms of manpower and financial cost. A cost-benefit analysis undertaken by Green (2011) makes it clear that the regular application of soap-spray necessary to keep scale at bay would not be economically viable over large areas of pineyard or prolonged timeframes.

Therefore, if future PMP analyses advocate clearance and soap-spray as an effective treatment, transect data on age-structure and pine health collected by Green (2011) and Mark (2012) should be used to prioritise areas of pineyard most likely to regain reproductive health. Alternatively, treatment could be employed only in restoration plots such as those established on Pine Cay this year (Hudson, 2012) to ensure continued health of re-introduced pines. Nursery pines have a high degree of health thanks to favourable nursery conditions and treatment with Malathion insecticide prior to planting (Hamilton et al. 2012), thus may have a greater resistance to scale. As
such, it might be possible to reduce concentration or frequency of any preventative soap-spray applications, reducing expenditure.

5.1.3 Strengths and Limitations

A key limitation to the analysis was the need to use mean average of each response variable per plot to account for in-plot pseudo-replication (Crawley, 2007). This gave only nine data-points for each variable, reducing the power of subsequent tests to detect significance within the data (Crawley, 2007). In an ideal world, multiple PMPs of each treatment would exist per island, increasing number of useable data-points. This is impossible due to limited area (Earle-Mundil, 2010) and varied vegetation structure of pineyards (Green, 2011) meaning that even if there were space for numerous plots per island, they would not be subject to the same ecological conditions, and thus useless as replicates.

There is still subjectivity in data-collection methodology, despite consistency of assessment methods used. Scale, mould and canopy loss are judged “by eye to nearest 5%” (Earle-Mundil, 2010) so some subjectivity between collectors is expected. Even data collected by the same person will have some inconsistency, as from personal experience (TCI, 2012) it takes practice to judge levels of these variables efficiently and consistently. However, “canopy loss” without doubt requires a standard definition, given the dramatic and unlikely fluctuations recorded between 2010-11 and 2011-12.

Despite these limitations, data collected from 2010-12 are sufficient to make future management suggestions, and highlight the need for the further work detailed below.
5.1.4 Suggestions for Further Research

Besides a further year of PMP monitoring, an investigation into environmental factors affecting pine health between islands is needed. Statistical analysis found that island was a significant factor in changes of all but one response variable (Table 4.1). It is believed that presence of a large underground freshwater lens contributes to the healthier state of Pine Cay pines (Hamilton et al. 2007). It would be useful to quantify how much hydrology contributes to relative pine health between islands. This could also prove useful in combination with ground-truthing in Conch Bar pineyard to see if there is an association between clusters of healthy pines (pers. obs. Jun-July 2012) and groundwater, or whether their health is due to an intrinsic quality of the pines themselves, such as level or type of defensive volatile chemical (Green, pers. comm., 2012).

Additionally, new collectors inexperienced in pine assessments could benefit from a brief pre-monitoring period on-site in the pineyards to practise judging levels of subjective variables by eye. This will improve consistency between initial and later recordings.
5.1.5 Effects of Parasitic/Competitor Plants on Scale Infestation

The significant association found between plot treatment and the presence of parasitic/competitive plants on pines shows that broadleaf clearance clearly reduces incidence of these plants, as anticipated. It also appears that this positive effect may be increased when clearance is combined with soap-spray application.

The lack of a significant association between presence of parasite/competitor and yellowing needles (Table 4.2) suggests that these plants do not have a significant impact on pine health. However it seems likely that parasitism by *C. filiformis* or competition by *A. berteroi* or *J. havanensis* does have some negative effect, as the very nature of parasitism causes stress to the host (Nelson, 2008), as does competition for light. It may be that this test did not pick up on these negative effects because of the plethora of variables currently impacting pine health, including shading by other plants, sooty mould and the scale insect itself. It may be that further data on plant shading for example are needed to disentangle this complex synergy of stressors.

Unexpectedly, a significantly greater number of pines with parasitic/competitor plants also had high levels of scale (Fig. 4.2). These data would appear to support the theory of an increase in herbivorous insects due to weakening of host defences by the plants (Runyon et al. 2007) rather than increased host health brought about by plant removal (Bass et al. 2002). However, a single year of data provides only a snapshot of ongoing interactions, so the question “Do the presence of the parasitic/competitor plants growing on pines have an effect on scale infestation?” cannot be answered with confidence yet.

5.1.6 Implications for Management

Taken as they are, the results displayed in Table 4.1 support previous suggestions (Section 5.1.1; Green, 2011) that it is application of soap-spray which generates the greatest positive effect on pine health, rather than clearance alone. However, this
does not take into account parasite-herbivore interactions on either side of the “snapshot” under scrutiny here.

Conversely, if considered in the context of wider interactions, they may be used to address a theory proposed by Green (2011), that the rise in scale and mould in clearance-only plots (in the absence of soap-spray to combat the insect) between 2010-11 could be direct result of the treatment itself; that CPRP staff could be acting as vectors for the scale.

As previously mentioned, decrease in mean scale and mould seen in this year’s assessments in clearance plots appears largely due to death of heavily-infested individuals, but if clearance were spreading scale then such a dramatic decrease might have been moderated by continued introduction of more insects by CPRP staff. Hamilton, (pers. comm. 2012) thinks human dispersal unlikely, but further research into scale lifecycle is needed for confirmation.

If the parasite-herbivore interactions described by Bass et al. (2002) do indeed relate to scale infestation of the Caicos pine, it may be that clearance does have a knock-on effect, but on parasitic/competitor plants rather than as an avenue of introduction. Green may have been seeing the effects of a year of clearance boosting pine health and making these pines more attractive to scale as a food source (Awmack and Leather, 2002). If so, application of soap-spray would account for the lower infestation levels seen in plots receiving this treatment, as scale would be discouraged, despite the similarly improved pine health through clearance of parasites/competitors.

In this case, plant-affected pines recorded in 2012 should have corresponding low levels of scale, thus the data do not appear to support this theory. However, it may be that initial plant removal 2010-11 was successful in increasing pine health, triggering an increase in scale, and plants recorded this year are re-growth, as mechanical clearance involves cutting rather than uprooting (Manco, pers. comm., 2012).
5.1.7 Strengths and Limitations

The overarching limitation to the interpretations outlined above is their foundation on a single year of data. Thus all theories must bear in mind that the data are not fully representative of the likely breadth of interactions taking place; the picture is incomplete.

5.1.8 Suggestions for Further Research

Further years of presence/absence data for parasitic/competitor plants on PMP pines are required to fully address the research question posed above, and reliably determine whether or not removing these plants through broadleaf clearance triggers a significant increase in scale infestation, and as such, should be discontinued as a scale-control technique. These data should be collected alongside recordings of other variables likely to be affecting pine health, including “shading by other plants”, particularly if yellowing needles remain the standard diagnostic for ill-health.
5.2 Controlled Burn

5.2.1 Broadleaf Control

Although ground cover returned to pre-fire levels in the weeks following the controlled burn, it is also evident from Fig. 4.4 that the burn was effective at reducing canopy density in the fire plots. Since pine population decline means the term “canopy” in Conch Bar pineyard now overwhelmingly refers to broadleaf species, the dramatic decline of this variable post-burn in plot 1 is promising. That this plot showed the greatest decrease is also significant, as it contained an area of dense coppice, in comparison to plot 2, which showed minimal change in its already sparse canopy. The resurgence in ground cover and the post-fire increase in species-richness are probably not as discouraging as would appear; together, these variables indicate post-fire increase in herbaceous species, demonstrating the positive effects of nutrient-rich ash on small plants. This phenomenon would also benefit sprouting pine seedlings, if future ground-truthing of Conch Bar were to find mature pines with the potential for seed banks which could then be targeted for controlled burns.

The return of canopy density of the control plot to pre-fire levels within a matter of weeks suggests that this plot’s “clearance” was likely the result of superficial loss of scorched foliage rather than the longer-lasting pruning desired. In addition, compared to the rapid, steep decline in fuel level seen in plots 1 and 2, the steady decrease observed in the control plot over the survey period suggests that fuel in this plot did not burn as successfully in the absence of pre-fire manipulation. Thus it appears that manual fuel-spreading prior to burns is required to ensure fire continuity across bare ground.
5.2.2 Pine Fire-Resilience

It is now possible to answer the research questions:

- Was there significant fire-induced mortality amongst fire plot pines?
- Were certain age classes more susceptible?
- Does pre-fire clearance around pines affect mortality?
- Does scale infestation affect pine fire-resilience?

Scorch-induced mortality was highest amongst seedlings (34.2%), but it seems that the controlled burn did not cause significant mortality amongst plot pines. Age-class was not a significant factor in scorch-mortality, however the significant increase in mean distance to nearest seedling (Fig. 4.5) in plot 1 after the burn suggests seedling mortality was somewhat greater than that of saplings, which showed no such distance increase.

There was no significant association found between fire plot and mortality, however Fig. 4.8 shows that mortality was greatest in plot 2. It is likely that this is the result of pine proximity to the numerous “jackpots” (large piles of broadleaf cuttings) which concentrated pockets of intense fire than shallower fuel spread evenly throughout the plot.

Figure 5.1 A jackpot in Middle Caicos fire plot (J. O’Brien, 2012)
The significant difference between scale infestation level of scorch-victims versus scorch-survivors suggests a higher level of scale does reduce pine resilience to fire. This is an important implication for management – when selecting areas of pineyard in which to carry out controlled burns, it will be necessary to first gauge the average scale level of pines in the area under consideration.

5.2.3 Implications for Management

It is apparent from the analysis that infestation by scale has affected pine fire-resilience. In light of this, suggesting wide-spread use of a management technique with potentially negative side-effects for individuals which are the focus of the conservation, particularly when the suggestion is based on a single trial with limited sample size may seem over-confident. However, when conserving a declining population there is often not time (Blumstein, 2006) for numerous management trials, and given the Caicos pine’s rapid decline since 2005, it is clearly vital to act.

Therefore, controlled burning is advocated as a broadleaf management technique, but it is recommended that burn sites with lower levels of scale be targeted first. Given that limited manpower, finances and access to water in TCI pineyards mean that prescribed burning will probably not be viable for entire pineyards, the CPRP will have to be selective anyway. Also, to target areas for pine regeneration, transect data from 2011-12 should be used to select areas with reproducing mature trees and hence potential seed banks.

Pine Cay has the greatest number of mature trees (Green, 2011), but controlled fire will have to be proposed to the homeowners as a management technique, which may meet with refusal (Hamilton, pers. comm. 2012). Burning in North Caicos is not practical due to the inaccessibility of Bottle Creek pineyard. In addition, pines here are so badly infested (Hamilton et al. 2012), and the succession of broadleaf so great that it would likely be unsuccessful; a fast surface fire as carried out at Conch Bar would either not burn sufficient broadleaf, or could become dangerously intense due to the large numbers of palms, which are highly flammable (O’Brien, pers. comm. 2012). The Ready Money end of North Caicos pineyard is accessible by road, but the virtual
disappearance of all the pines as a result of the 2009 escaped fire would make a prescribed burn futile. Therefore Conch Bar pineyard should be targeted first for broadleaf control, as it has the greatest accessibility and clusters of healthy pines, with some mature trees remaining (Green, 2011; pers. obs. 2012).

5.2.4 Strengths and Limitations

It is possible that there is an association between age class and mortality from combustion, and indeed this is well-known (Mitchell et al. 2009) but this dataset does not allow that to be tested, because for the pines tagged pre-fire, there were no deaths from combustion – all these pines were still alive in the first post fire assessment.

Analysis of pine combustion mortality from PCQ data was not possible due to inconsistency of recording – time limitations before the burn necessitated data-collection by numerous collectors, using different measuring equipment (callipers versus DBH tape) and leading to some imprecision and inconsistency between assessments.

It would have been useful to get an indication of whether 1m clearance around seedlings prevented combustion, but since mortality of youngest seedlings is common in healthy pineyards (O’Brien et al. 2008; Mitchell et al. 2009), where there is less broadleaf around seedlings anyway, it is likely some would have died despite pre-fire management.

5.2.5 Suggestions for Further Research

The PCQ method should be repeated on future controlled burns, in pursuit of combustion mortality data. However, to minimise unreliability and maximise precision, standard practice should be pre-agreed with all collectors, and these same collectors should undertake each of the time-series assessments. Callipers should be used for basal DBH, and tape for DBH at breast height.
It would be useful also to map any “jackpots” in ArcPad, along with individual plot pines, so that the effect of proximity to jackpots on mortality and scorch can be quantified.
6. ADDITIONAL OUTPUTS

Pine density transects were carried out in previously “unexplored” areas of pineyard on North Caicos, Middle Caicos and Pine Cay to supplement and increase reliability of current estimates of population size, age structure and decline of the Caicos pine on each island. Twelve transects were carried out on each island, each containing five sampling points, spaced 50 metres apart.

To allow this year’s data to be combined with the existing dataset, transect methods were, as far as possible, consistent with those used by Green in 2011. Criteria for transect placement were as follows: 1) transects must be within mapped pineyard boundaries as delineated by Hamilton et al. (2010) and 2) approximately 200m away from all previous transects.

Transects were carried out with the assistance of Alex Hudson (IC), and fulfilled the dual purpose of collecting pine population data and investigating distribution and biodiversity of invertebrate predators (for details, see Hudson, 2012). Full species lists were recorded for each transect point on all islands, for use in future vegetation mapping. Due to time constraints, transect data were not analysed, but will be made available to the CPRP and RBGK.
REFERENCES


# Appendix 1 - Social Survey Reproduced from Excel Spreadsheet

## Background Information
Hello, we are students working with the Caicos Pine Recovery Project, trying to conserve the Caicos pine. We would like to find out more about people’s use of fire in TCI. Do you have a couple of minutes to answer some questions? This is anonymous and we won't share your answers with anyone else.

<table>
<thead>
<tr>
<th>Have you heard about the Caicos Pine Recovery Project?</th>
<th>Y ...</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>It's a project working to protect the Caicos pine, which is TCI's national tree. The pines are declining due to an invasive insect pest, and the project is exploring ways to keep the pineyards on North, Middle and Pine Cay healthy for the future.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Which island do you live on?</th>
<th>NC</th>
<th>MC</th>
<th>PC</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>And have you lived there your whole life?</td>
<td>Y</td>
<td>N ...</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>How old are you?</th>
<th>≤ 19</th>
<th>20-29</th>
<th>30-39</th>
<th>40-49</th>
<th>50-59</th>
<th>≥ 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>What do you do?</td>
<td>......</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Which island do you work on?</th>
<th>NC</th>
<th>MC</th>
<th>PC</th>
<th>Other</th>
<th>Retired</th>
<th>Don’t work</th>
</tr>
</thead>
</table>

Now I’d like to ask you some quick questions about how you use fire.

Do you ever light fires outdoors for any of the following activities:

- To clear land for farming or building-work
- To make charcoal
- To burn garbage or trash
- For recreation e.g. Cooking fires or bonfires
- Any other reason =

None of the above (go to pineyard mgmt tab)
<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>What do you use the land for once it’s cleared?</td>
<td>Agriculture (which crops?)</td>
</tr>
<tr>
<td></td>
<td>Building-work</td>
</tr>
<tr>
<td></td>
<td>Other ...</td>
</tr>
<tr>
<td>What time of year do you light these fires?</td>
<td>All year round</td>
</tr>
<tr>
<td></td>
<td>Wet season</td>
</tr>
<tr>
<td></td>
<td>Dry season</td>
</tr>
<tr>
<td>How often do you light fires for land clearance?</td>
<td>daily</td>
</tr>
<tr>
<td></td>
<td>weekly</td>
</tr>
<tr>
<td></td>
<td>monthly</td>
</tr>
<tr>
<td></td>
<td>every couple of months</td>
</tr>
<tr>
<td></td>
<td>twice a year</td>
</tr>
<tr>
<td></td>
<td>annually</td>
</tr>
<tr>
<td></td>
<td>every 2-5 yrs</td>
</tr>
<tr>
<td>Do you use any extra fuel?</td>
<td>No, just burn what’s there</td>
</tr>
<tr>
<td></td>
<td>Gasoline</td>
</tr>
<tr>
<td></td>
<td>Wood (cut logs)</td>
</tr>
<tr>
<td></td>
<td>Charcoal</td>
</tr>
<tr>
<td></td>
<td>Coal</td>
</tr>
<tr>
<td></td>
<td>Other ...</td>
</tr>
<tr>
<td>What do you use to light it?</td>
<td>Matches</td>
</tr>
<tr>
<td></td>
<td>Cigarette lighter</td>
</tr>
<tr>
<td></td>
<td>Matches &amp; gasoline</td>
</tr>
<tr>
<td></td>
<td>Cigarette lighter &amp; gasoline</td>
</tr>
<tr>
<td></td>
<td>Other ...</td>
</tr>
<tr>
<td>Roughly how big will the fire be?</td>
<td>...</td>
</tr>
<tr>
<td>Roughly how long will it burn for each time?</td>
<td>less than an hour</td>
</tr>
<tr>
<td></td>
<td>1-5 hrs</td>
</tr>
<tr>
<td></td>
<td>6-10 hrs</td>
</tr>
<tr>
<td></td>
<td>whole day</td>
</tr>
<tr>
<td></td>
<td>longer than a day</td>
</tr>
<tr>
<td>How do you stop the fire spreading?</td>
<td>cut a fire-break</td>
</tr>
<tr>
<td></td>
<td>ring of stones</td>
</tr>
<tr>
<td></td>
<td>limit the fuel</td>
</tr>
<tr>
<td></td>
<td>other ...</td>
</tr>
<tr>
<td>Can you tell me approx. whereabouts you light these fires?</td>
<td>...</td>
</tr>
<tr>
<td>For example, you could say &quot;between Conch Bar and Bambarra&quot;.</td>
<td></td>
</tr>
<tr>
<td>Or can you show me roughly on this map?</td>
<td></td>
</tr>
</tbody>
</table>
Remember, all your answers are totally anonymous.

**Charcoal-making**

<table>
<thead>
<tr>
<th>Question</th>
<th>All year round</th>
<th>Wet season</th>
<th>Dry season</th>
</tr>
</thead>
<tbody>
<tr>
<td>What time of year do you make charcoal?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How often do you make charcoal?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How often do you make charcoal?</td>
<td>every few days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How often do you make charcoal?</td>
<td>weekly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How often do you make charcoal?</td>
<td>monthly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How often do you make charcoal?</td>
<td>every couple of months</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How often do you make charcoal?</td>
<td>twice a year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How often do you make charcoal?</td>
<td>annually</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How often do you make charcoal?</td>
<td>every 2-5 yrs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What type of wood do you burn?</td>
<td>cedar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What type of wood do you burn?</td>
<td>mahogany</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What type of wood do you burn?</td>
<td>pigeon plum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What type of wood do you burn?</td>
<td>lignum vitae</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What type of wood do you burn?</td>
<td>lysiloma</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What type of wood do you burn?</td>
<td>wild oak</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What type of wood do you burn?</td>
<td>other...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Why that wood?</td>
<td>Best for charcoal-making</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Why that wood?</td>
<td>Available</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Why that wood?</td>
<td>Cuts easily</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Why that wood?</td>
<td>Other ...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is cedar good for charcoal-making?</td>
<td>Y</td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>If you could use any tree, what would you prefer to use?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you use any extra fuel?</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you use any extra fuel?</td>
<td>Gasoline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you use any extra fuel?</td>
<td>Old charcoal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you use any extra fuel?</td>
<td>Trash (dry veg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you use any extra fuel?</td>
<td>Other ...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What do you use to light it?</td>
<td>Matches</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What do you use to light it?</td>
<td>Cigarette lighter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What do you use to light it?</td>
<td>Other ...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roughly how long will it burn for each time?</td>
<td>1-5 hrs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roughly how long will it burn for each time?</td>
<td>6-10 hrs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roughly how long will it burn for each time?</td>
<td>whole day</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Does someone stay to keep an eye on the pit?

Y \quad N

How do you stop the fire spreading?

cut a fire-break
ring of stones
limit the fuel
other ...

Can you tell me approx. whereabouts you light these fires?
For example, you could say "between Conch Bar and Bambarra".
Or can you show me roughly on this map?
Remember, all your answers are totally anonymous.

Burning garbage / trash

What time of year do you burn garbage / trash?

All year round
Wet season
Dry season

How often?
daily
weekly
monthly
every couple of months
twice a year
annually

Do you use any extra fuel?

Y ...
N

What do you use to light it?

Matches
Cigarette lighter
Matches & gasoline
Cigarette lighter & gasoline
Other ...

Roughly how big will the fire be?

.....

Roughly how long will it burn for each time?

less than an hour
1-5 hrs
6-10 hrs
whole day
longer than a day

How do you stop the fire spreading?

limit the fuel
cut a fire-break (if in the bush)
ring of stones
Does someone stay to keep an eye on the fire?  
Y  N 

How do you extinguish the fire?  
Water  Sand/dust  Let it burn itself out 

Can you tell me approx. whereabouts you light these fires?  
For example, you could say “between Conch Bar and Bambarra”.  
Or can you show me roughly on this map?  
Remember, all your answers are totally anonymous. 

Recreation 
Recreational activity = cooking fire  Bonfire  Other ...  

What time of year do you light fires for recreation?  
All year round  Wet season  Dry season 

How often?  
daily  weekly  monthly  every couple of months  twice a year  annually 

What do you use for fuel?  
Coal  Charcoal  Wood (cut logs)  Trash  Other ... 

What do you use to light it?  
Matches  Cigarette lighter  Matches & gasoline  Cigarette lighter & gasoline  Other ... 

Roughly how big will the fire be?  
..... 

Roughly how long will it burn for each time?  
less than an hour  1-5 hrs  6-10 hrs  whole day  longer than a day
How do you stop the fire spreading?

limit the fuel
cut a fire-break (if in the bush)
ring of stones
other ...

If a bonfire, does someone keep an eye on it?  Y N

How do you extinguish the fire?

Water
Sand/dust
Let it burn itself out

Can you tell me approx. whereabouts you light these fires?
For example, you could say "between Conch Bar and Bambarra".
Or can you show me roughly on this map?
Remember, all your answers are totally anonymous.

Other activity

Fire-use activity =  .....  Wet season  Dry season

What time of year do you light fires for recreation?
All year round

How often?
daily
weekly
monthly
every couple of months
twice a year
annually

What do you use for fuel?
Coal
Charcoal
Wood (cut logs)
Trash
Other ...

What do you use to light it?
Matches
Cigarette lighter
Matches & gasoline
Cigarette lighter & gasoline
Other ...

Roughly how big will the fire be?  .....  

Roughly how long will it burn for each time?  less than an hour
How do you stop the fire spreading?

- limit the fuel
- cut a fire-break (if in the bush)
- ring of stones
- other ...

(If applicable) Does someone stay to keep an eye on the fire?

Y  N

How do you extinguish the fire?

- Water
- Sand/dust
- Let it burn itself out

Can you tell me approx. whereabouts you light these fires?

For example, you could say "between Conch Bar and Bambarra".

Or can you show me roughly on this map?

Remember, all your answers are totally anonymous.

**Pineyard management**

These last questions are about the pineyards on North, Middle and Pine Cay.

Have you ever been to any of the pineyards in TCI?

Y  N

Have there been any pineyard fires in the last 10 years?

Y  N

If yes, which pineyard?

...  

If yes, do you know if the fire was natural or was it caused by people?

- Natural
- Caused by people
- Don’t know

In your opinion, which of the following fire sources poses the most threat to TCI pineyards?

- Natural fire - e.g. Lightning strike
- People lighting fires for agriculture (slash and burn farming)
- People lighting fires for recreation (cooking outdoors etc)
- People lighting fires to make charcoal
- People burning trash / garbage
- Other ...
Do you think there is a risk of human-ignited fires spreading to pineyards?  

Y  N

Which pineyard do you think is most at risk from fire?  

Conch Bar (Middle pineyards)  
Bottle Creek  
Ready Money  
Pine Cay

Why is that?

In your opinion, do the pineyards need to be burned occasionally to stay healthy?  

.....

Do you think the pineyards in TCI need some kind of professional management to control bush (broadleaf) vegetation?  

Y  N

If yes, do you think controlled burns would be a good way to do this?  

Y... N... (why not / what other method?)

Do you think it is important that the pineyards are conserved?  

Y... N... (why not?)

Do you have any comments about anything we've just discussed?  

Y... N

Would you be interested in finding out more about the Caicos pine project?  

Y  N

If yes, what is the best way for the Pine Project to reach more people?  

Newspaper articles  
Community meetings  
School visits  
Questionnaire surveys  
In Creole?  
Other ...

Thankyou very much for taking the time to talk to us!
Appendix 2 – TCI pineyards (red) – pineyard location and extent mapped in ArcPad (Hamilton, 2007)

Pine Cay pineyard [left]

Caicos Bank, satellite image [above]

Conch Bar pineyard, Middle Caicos [below]

Bottle Creek (north) and Ready Money (south) pineyard, North Caicos [right]