Recovery of the endemic Caicos Pine

Invasive pest management and restoration

Alex Hudson

4/9/2012

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science and the Diploma of Imperial College London
Recovery of the endemic Caicos Pine: Invasive pest management and restoration

Contents

List of acronyms .......................................................................................................................... 5
Abstract ........................................................................................................................................ 6
Acknowledgements ..................................................................................................................... 7
1. Introduction .............................................................................................................................. 8
   1.1 The Turks & Caicos Islands ................................................................................................. 8
   1.2 The Caicos Pine .................................................................................................................. 9
   1.3 Policy and research .......................................................................................................... 10
      1.3.1 Research ................................................................................................................... 11
      1.3.2 Policy ....................................................................................................................... 11
   1.4 Project Aims and objectives ............................................................................................. 12
2. Background .............................................................................................................................. 14
   2.1 The Turks & Caicos Pineyards ......................................................................................... 14
      2.1.1 Middle Caicos (Figure 2.1) ..................................................................................... 14
      2.1.2 North Caicos (Figure 2.2) ..................................................................................... 15
      2.1.3 Pine Cay (Figure 2.3) ............................................................................................. 16
   2.2 The Caicos Pine ................................................................................................................ 17
   2.3 Invasive species .............................................................................................................. 17
      2.3.1 Trade ....................................................................................................................... 17
      2.3.2 Islands .................................................................................................................... 18
      2.3.3 Controlling or eradicating invasives ......................................................................... 18
      2.3.4 The Scale insect ....................................................................................................... 20
      2.3.5 Restoration Ecology ................................................................................................. 22
3. Methods .................................................................................................................................. 26
   3.1 Insect transects .............................................................................................................. 26
      3.1.1 Data analysis .......................................................................................................... 28
   3.2 Restoration plots ............................................................................................................ 29
3.2.1 Data analysis ..................................................31
3.3 Fire plots ..................................................................32
  3.3.1 Data analysis ..................................................34
4. Results .......................................................................35
  4.1 Insect data ............................................................35
    4.1.1 Lacewing eggs .................................................35
    4.1.2 Spiders ..........................................................38
    4.1.3 Lacewing larvae ..............................................40
  4.2 Restoration plot results ...........................................43
  4.3 Fire data ..............................................................45
    4.3.1 The initial 30 ....................................................45
    4.3.2 All post fire scorched trees ..............................45
    4.3.3 Most scorched trees .........................................46
    4.3.4 Least scorched trees ........................................47
    4.3.5 Scorch variation ..............................................47
5. Discussion .............................................................51
  5.1 Insects on Caicos Pines ...........................................51
    5.1.1 Island differences .............................................51
    5.1.2 Association with tree density ............................51
    5.1.3 Association with scale ......................................51
    5.1.4 Biocontrol .....................................................52
    5.1.5 Aphids ..........................................................52
    5.1.6 Experimental limitations and improvements ........52
    5.1.7 Further investigation ........................................53
  5.2 Fire .................................................................54
    5.2.1 Experimental limitations and improvements .......54
  5.3 Restoration ..........................................................54

Alex Hudson
List of acronyms

AIC - Akaike Information Criteria

ANOVA – Analysis of Variance

CBD – Convention on Biological Diversity

CPRP – Caicos Pine Recovery Programme

DBH - Diameter at breast height

DECR – Department of Environment and Coastal Resources (TCI government)

FAO – Food and Agriculture Organisation

GLM – Generalised Linear Model

GPS – Global Positioning Satellite

IS – Invasive Species

IUCN - International Union for Conservation of Nature

MAB – Man and the Biosphere

MEA – Millennium Ecosystem Assessment

SERI – Society of Ecological Restoration International

TCI – Turks & Caicos Islands

UNESCO – United Nations Educational, Scientific and Cultural Organisation

UK – United Kingdom

US – United States of America
Abstract

The Turks & Caicos national tree, the endemic Caicos Pine is under threat of extirpation from the invasive Pine Tortoise Scale which has caused dramatic declines in numbers and fecundity over the past ten years. This paper explores two aspects of fighting the pines demise, dealing with the invasive species and helping put the pine spread back in the wild. The local ecosystem was explored for the option of a biological control agent already in the environment looking for a relationship between the two species abundance. Of the insects found Lacewing larvae proved to have the strongest association with increasing scale infestation on pine trees which suggests it to be a strong candidate for a future biological control agent with further research. As part of this thesis a restoration plot was also set up in Pine Cay planting out 75 pine trees from the government nursery. The baseline data for these were collected so that the success of the plots may be monitoring in future. Cages have also been set up surrounding some randomly selecting pines to investigate the possible vectors of spread of the pine in order to improve management in future.
Acknowledgements

I would like to thank the sponsors and partners involved in this project, The Royal Botanic Gardens, Kew, Imperial College London, Chester Zoo, The Whitley Fund for Nature and the Turks & Caicos government for allowing us to study the Caicos Pine and to see the country. Thank you also to the United States Forestry Service for providing us with the expertise to carry out the first controlled fire on the Turks & Caicos Islands.

I would especially like to thank my supervisors Martin Hamilton and Colin Clubbe for all their help, advice and support throughout the time in the field and during daunting task of writing up. Marcella Corcoran, Bryan Naqqi Manco & Junel ‘Flash’ Balsie all deserve a special thanks for their untiring help in the field identifying plants, setting up experiments, keeping spirits high and forgiving misjudged actions (Swamp driving?). Thank you also to the rest of the local governmental staff too who provided various levels of support throughout the trip.

Thanks to the experts who visited with us: Joe O’Brien, David Grimm & Ben Hornsby from the U S Forestry Service for providing us with their time to carry out a controlled burn, for teaching us all about fire ecology and for helping us to design experiments around their work; Paul Green and Martyn Ainsworth from Kew for providing us with an insight into their work with mycorrhiza and plant chemistry; and Chris Malumphy from FERA for his valuable insights into scale insect ecology and his help in designing my insect collection methodology.

Finally thank you to all the other Con Sciers, everyone at Silwood and of course the William Penney gang for a year of hard work and fun.
1. Introduction

1.1 The Turks & Caicos Islands
The Turks & Caicos Islands (TCI) are part of the Caribbean region, one of 25 biodiversity hotspots outlined by Myers et al. (2000). Hotspots were chosen based on exceptional numbers of endemic species, the size of the area of land and level of threat with the Caribbean containing only 11.6% of primary vegetation remaining in a land area of 263,500km$^2$ (Myers et al., 2000). Refugia are all that remain, susceptible to extirpation from random natural events and development (Eckehard et al., 2008; Maunder et al., 2008) making them prime candidates for conservation actions.

On TCI there are nine plant and eight herpetofauna species endemic to the islands (Oldfield & Sheppard, 1997) with a further 40 found endemic to the archipelago. They are home to one of the UK’s most natural wetlands currently listed under the Ramsar Convention (Pienkowski, 2005). They are also home to the rare pine rockland habitat found in Florida, and other Caribbean islands.

Tourism and traditional coastal industries are a major threat to the islands (Oldfield & Sheppard, 1997; Zuidema et al. 2011), putting pressure on groundwater reserves and quality (Gossling, 2001; Kahoru & Yap, 2001). One of the main TCI tourism slogans is “Beautiful by nature” which might suggest a drive to conserve the natural environment is inherent in the tourist development culture (Zuidema et al. 2011), however this is subject to interpretation and may be measured by how a tourist judges beauty and what is natural, focusing on stretches of white beach and clear turquoise sea (McQuillan, 1998). Maintaining this false image of nature could provide problems for conservation as resources are diverted away from inland areas and as environmental damage ensues from development activities e.g. dredging of sea grass (Zuidema et al. 2011).

Protection of biodiversity is important however because losses through human influence, are associated with a loss in ecosystem goods and services, and ecosystem properties (Chapin et al., 1997; MEA, 2005; Hooper et al., 2005; Balvanera et al., 2006). These altered systems are more susceptible to damage from changes in biotic and abiotic conditions, including attack by invasive species (IS)(Chapin et al., 1997; Hooper et al., 2005).
1.2 The Caicos Pine
The Caicos pine (Pinus caribaea Morelet var. bahamensis (Griseb.) W. H. Barrett & Golfari) is a hard pine variety of the Caribbean pine (Pinus caribaea) endemic to the Bahamas and the Turks & Caicos Islands (See figure 1). It occurs on four islands in the Bahamas and three in TCI and is the latter’s national tree (Malumphy et al., 2012). A recent assessment of the Caicos pine classified it as Vulnerable using criteria A1c + 2c in the 1994 categories and criteria (version 2.3) which states it has seen a “decline in area of occupancy, extent of occurrence and/or quality of habitat” (A1c) and a “reduction of at least 80%, projected or suspected to be met within the next 10 years or three generations, whichever is the longer” (A2c) (IUCN, 2012). Threats come from human development, climate change and the recent invasion of a pine tortoise scale insect (Toumeyella parvicornis (Cockerell)) thought to have been brought over from North America by the Christmas tree trade (Malumphy et al., 2012).

Figure 1: Map of the locations of the Caicos pine

The Pine Tortoise scale insect feeds on the sap of the pines reducing their resilience and fecundity. It also emits sugary honeydew onto needles and surrounding plants attracting a black sooty mould which reduces the light reaching the pine needles and so lowering their rate of pine photosynthesis (Malumphy et al. 2012). As with many other introduced pests (Waring & O’Hara, 2005) the insect’s success has led to a reduced vigour and seed production and has helped contribute to dramatic 90% decline in mature trees in some areas which could lead extirpation in TCI (Green, 2011; Malumphy et al., 2012).
A secondary affect of the insect is a lack of pine regeneration. Large uncontrolled crown fires, similar to those seen in other disturbed fire dependent habitats (Allen et al., 2002; O’Brien et al., 2008), have wiped out many seedlings, young saplings and mature trees already weakened by the insect. Combined with reduced fecundity plants scrub growth is increasing acting as a barrier to succession (Dobson et al., 1997).

Whilst fluctuating populations of single species may be expected in some cases of increasing biodiversity (Tilman, 1996; Balvanera et al., 2006), as the dominant and defining species within the pine forest pine loss would have a highly detrimental effect to the ecosystem (Waring & O’Hara, 2005; Oldfield, 2009) including knock on effects to other forest wildlife, such as the Globally Vulnerable migrating Kirtland’s Warbler Dendroica kirtlandii (Pienkowski, 2005; Manco, 2008); and other environmental conditions, such as soil stability and water table effects (Dawson, 1993).

The pine is now a priority for conservation action by the TCI Department of Environment and Coastal Resources (DECR) with the establishment of the Caicos Pine Recovery Program (CPRP) in 2008, charged with ensuring pine survival and persistence through in situ and ex situ measures (Malumphy et al., 2012).

1.3 Policy and research
With increasing awareness and understanding of the negative effects of human resource use a change in attitudes towards the environment has grown (Grove, 1995). On an international scale agreements have been formed which: attempt to change damaging practices to the environment, such as Convention on Biological Diversity (CBD) (CBD, 2005) and the RAMSAR convention (Convention on Wetlands, 1971)(Oldfield & Sheppard, 1997); create protected areas, such as Special Areas of Conservation through the Habitats Directive (Habitats Directive, 1992) and the establishment of Biosphere reserves by UNESCO’s Man and the Biosphere (MAB) Programme (UNESCO, 2008); and establish means to analyse and protect the most vulnerable species alive today, such as IUCN red listing (IUCN, 2012).

Further integration into national policies and strategies help change behaviours in order to achieve conservation success (Schultz, 2011). A good scientific backing is required regarding: problems with species or habitats in decline, the relative importance of conservation concerns in terms of what they provide (i.e. economic or systemic...
Recovery of the endemic Caicos Pine: Invasive pest management and restoration

importance) and how dyer the situation is (i.e. closeness to extinction for a species) and evidence for methods which will successfully achieve conservation goals.

1.3.1 Research

Two principal areas of research are important to conservation development in TCI: tackling IS and habitat restoration.

IS are one of the five major threats to global biodiversity with expected to worsen with increasing globalisation (Williamson & Fitter, 1996; Waring & O’Hara, 2005; Hulme, 2009; Bradley et al., 2012). Their management is difficult and eradication can be impossible once they are established. It is then necessary to find ways of controlling them to reduce their negative environmental affects (Waring & O’Hara, 2005). Pesticides have been tried but have knock on affects for other species, including predatory insect populations (Clarke et al., 1988; Bengtsson et al. 2005), so that research which looks into ways of managing IS in other ways is important, especially if transferable to other situations (Waring & O’Hara, 2005). A better understanding of invasion ecology should help to halt the decline of the species and to aid in creating successful restoration projects in future (Waring & O’Hara, 2005).

Research into methods for restoration will become more significant in future, especially in arid environments, in order to attempt to halt large scale mortality in reforestation projects (Gomez-Aparicio et al., 2004). Cost effective options which promote natural regeneration and processes are required (Maunder et al., 2008) with baseline surveys and monitoring allowing greater synthesis of the impacts of planted trees (FAO, 2006). Careful analysis should increase success and maintain openness to adaptive management techniques (Allen et al., 2002).

1.3.2 Policy

Future proof environmental and management policy will need to address biosecurity and habitat restoration in TCI (Lodge et al., 2009). Biosecurity is important for halting IS global spread but is often hard to enforce because a lack of knowledge and resources, especially on islands like TCI where boats are important for travel and goods importation. Research of the issues highlights the problem and may help refine policy on international quarantines and monitoring on potential entry points of IS in future – targeting these is seen as a good strategy for stopping arrival of future pests (Waring & O’Hara, 2005). This could include better risk assessment, based on likely characteristics of IS to TCI similar to the
‘black list’ already used around the world, with tighter trade regulations (Pheloung et al. 1999; Perrings et al. 2005; Hulme, 2009; Bradley et al., 2012)

Oldfield (2009) points out that Article 9 of the CBD (CBD, 1992) stresses the importance of ex situ conservation predominantly for the purpose of complementing in situ measures matching the ecosystem approach to conservation. Monitoring and management of pilot restoration areas provides this allowing the future investigation of any possible factors which lead to success or failure in re-wilding, judged by tree survival on a local scale. This data may then be used to create sturdier management plans and standards for future restoration projects making them more cost effective. The UK government, meanwhile, gets the opportunity to provide the resources greatly needed for policy development in a place of global importance for biodiversity (Oldfield, 1997; Myers et al., 2000).

Planting projects will become more important in future for two reasons: firstly as an environmental restoration activity and secondly in response to climate change (Oldfield, 2009), possibly as part of an assisted migration or colonisation program to areas without reproducing adult pines (Hoegh-Guldberg et al., 2008; Vitt et al., 2010).

**1.4 Project Aims and objectives**
The aims of this project are to build on previous project work to develop a comprehensive understanding of the morphological and ecological data that will be useful in guiding management of the TCI pineyards (Earle-Mundin, 2010; Green, 2012). Specifically this project aims to discover possible “natural” methods for managing the pine tortoise scale insect so that infestation levels may be reduced in future without the use of pesticides (Bengtsson et al. 2005). The two methods investigated are biological controls and fire management.

The project will also set up a pilot restoration area for planting of ex situ nursery trees back into the wild helping the TCI and the UK government implement the CBD (Oldfield & Sheppard, 1997) whilst allowing the investigation of pine characteristics that could lead to survival success and invasion biology of the pine tortoise scale insect.

The results of this analysis will be fed directly into TCI policy makers through the TCI Department for Environment and Coastal Resources (DECR) allowing them to act appropriately with their conservation activities.

In this study the following questions are addressed

---

Alex Hudson
1. Are there some of the usual natural predators present on pine trees in the ecosystem already.
2. Do these predators eat scale insect or is their presence associated with scale?
3. Does fire reduce scale infestation on trees?
4. Do wire cages and/or wire cages with fly mesh wire around planted trees reduce scale infestation susceptibility by acting as a barrier to animal vectors such as birds and lizards and wind respectively?
5. Are there any seedling or sapling characteristics more susceptible to death or better able to survive replanting into the wild from the *ex situ* government nursery?
2. Background

2.1 The Turks & Caicos Pineyards

2.1.1 Middle Caicos (Figure 2.1)

Figure 2.1: A map of the Middle Caicos pineyards

2.1.1.1 Fire plots
The ground is limestone rock interspersed with shallow soil cover. The vegetation is of tropical dryland type with typical species to be found including Sabal palmetto (Walter) Lodd. ex Schult. & Schult.f., Thrinax morrisii H. Wendl., Ernoda serratifolia Correll, Coccoloba uvifera (L.) L., Tabebuia bahamensis Northr. and Randia aculeate L. as well as Pinus caribaea var. Bahamensis (Griseb.) W. H. Barrett & Golfari although much of the older trees of the pine stand as dead wood.

2.1.1.2 Transects
The Middle Caicos pineyard is made up of a large area of low lying (0.30m-50m) vegetation of Cassytha filiformis L., Angadenia berteroi (A. DC.) Miers, Sabal palmetto (Walter) Lodd. ex Schult. & Schult.f., Randia aculeate L., Swietenia mahagoni (L.) Jacq., Coccoloba uvifera (L.) L., Ernoda serratifolia Correll, Mosiera longipes (O. Berg) Small. Some areas had a lot of Cladium jamaicense Crantz, Byrsonima lucida (Mill.) DC. and Rhynchospora floridensis (Britton ex Small) H. Pfeiff. but these were not recorded as much. Within this was a mosaic of areas with taller and thicker vegetation (2-4m tall), harder to travel through. These included more Acacia chorphylla Benth., Acacia acuifera Benth., Cassia caribaea Northr. (synonym of Chamaecrista caribaea (Northr.) Britton. (The Plant List, 2010)), Lystoloma latissilquum (L.) Benth., Smilax auriculata Walter,
Smilax laurifolia L., Thrinax morrisii H. Wendl., Swietenia mahagoni (L.) Jacq., Metopium toxiferum (L.) Krug & Urb., Reynosia septentrionalis Urb. All areas had bare limestone rock, particularly in the low lying areas. In the low lying area there were further areas with ditches which contained water pools. C. jamaicense Crantz was often associated with these with taller S. palmetto (Walter) Lodd. ex Schult. & Schult.f. trees.

Pinus caribaea var. bahamense (Griseb.) W. H. Barrett & Golfari were found mainly in the larger areas of low lying vegetation, with a few still found in parts of the clumps of taller vegetation. Most found were young seedlings and sapling, however in areas surviving mature and young trees could also be found, sometimes in clumps with 5 or 6 in a 20m radius. One noteworthy area was found with healthy mature, and many young trees and saplings in a circa 50m radius.

2.1.2 North Caicos (Figure 2.2)

Figure 2.2: A map of the North Caicos pineyards

Much of the pineyards in North Caicos had much thicker and taller vegetation than North with large areas with canopy 2m-6m high, often with Acacia sp., Lysiloma latisiliquum (L.) Benth. and Mimosa bahamensis Benth. and not easily travelled through. Other areas found had lower vegetation cover (0.50m–2m - though still often thicker than Middle Caicos) being made up mostly of palm species Sabal palmetto (Walter) Lodd. ex Schult. & Schult.f. and Thrinax morisii H. Wendl.. Pinus caribaea var. bahamense (Griseb.) W. H. Barrett & Golfari was found fleetingly with many dead stumps across the more open landscape.
2.1.3 Pine Cay (Figure 2.3)

Pine Cay is situated west of North Caicos. The pineyard is split into areas which flood and those that did not. The dominant species included *Tabebuia bahamensis* Northr., *Manilkara jaimiqui* subsp. *emarginata* (L.) Cronquist (Synonym of *Manilkara bahamensis* (Baker) J. J. Lam & B. Meeuse (The Plant List, 2010)), *Strumpfia maritima* Jacq. growing at a height of between 0.50m – 2m and *Rhynchospora floridensis* (Britton ex Small) H. Pfeiff. growing under this in places to about 0.25m. Within the wetland areas these were found to a lesser degree with more *Cladium jamaicense* Crantz, *Rhachicallis americana* (Jacq.) Hitchc. being dominant.

Pines are more prevalent as mature adults than they are in Middle and North pineyards. The soil is sandier with dune formations and dried lithified dunes inland. It is also a smaller island and has more salt spray and wind affecting plants leading to a slightly different plant community. The Cay also appears to have greater water availability with year round lakes and large flooded areas in summer (wet season).

2.1.3.1 Restoration plots

The soil was sandy and the plots are located near two old dune bars which have become lithified to produce harder ridge banks. The plots were manually cleared of most of the vegetation bar pines, leaving an open area with dotted *Thrincax morisi* H. Wendl. palms and *Moseira longipes* (O. Berg) Small.
2.2 The Caicos Pine
As the dominant species in the Turks & Caicos pineyard and as an endemic to the Caribbean islands the decline of the Caicos pine over the past seven years deserves conservation attention. There are three main factors standing in the way of this:

1. Reduction of an IS the pine tortoise scale insect
2. Restoration as the canopy tree in pineyards
3. A return of fire process to the system.

2.3 Invasive species

2.3.1 A consequence of trade
“Invasive species” are non native species, plants or animals, which are brought to a new environment by human actions, often via shipments or goods transportation (Hulme, 2009). They establish and spread prolifically causing a negative impact on the local ecosystem (Simberloff, 2006). In most instances, however, transported species do not represent a major extinction threat or cause ecological problems (Williamson & Fitter, 1996; Bradley et al. 2012; Davis et al., 2011). In fact they may confer benefits on the community, by increasing the local biodiversity and providing lost ecosystem functions (Sax et al. 2002; Denslow, 2003; Simberloff, 2006). These species may be separated from IS by the term “non-natives” (Schlaepfer et al., 2011).

Despite the relative safety of most species transportation the damage caused by IS has been suggested as one of the greatest threats to nature with cases of insect outbreaks on trees increasing (Oldfield & Sheppard, 1997; Waring & O’Hara, 2005). These have been associated with increasing globalisation and opening up of new trade partners making it easier to transport exotic species from new parts of the world into novel ecosystems (Perrings et al., 2005; Smith et al., 2007; Hulme, 2009; Bradley et al., 2012).

The ornamental plant trade industry has been a major source of insect pest and plant invasions in recent years as it has grown (Perrings et al., 2005). Imports of nursery plants into the US were valued at $250 million in 2010 and are increasing (Bradley et al., 2012). The trend is likely to continue and with climate change the types of plants traded are shifting towards drought tolerant species with the invention of new practices like xeriscaping (Bradley et al., 2012). In dryland habitats, like TCI, these species are likely to be able to thrive so their likelihood of becoming invasive is increased (Bradley et al., 2012).
Recovery of the endemic Caicos Pine: Invasive pest management and restoration

Increasing wealth on the TCI due to development and tourism (Zuidema et al. 2011) means that further IS occurrences could be expected without proper controls (Hulme, 2009; Bradley et al., 2012)

2.3.2 The trouble with Islands

Islands are more susceptible to invasive predators and pathogens than mainlands (Denslow, 2003; Davis et al., 2011; Schlaepfer et al., 2011). Simberloff & Von Holle (1999) suggest this is because they often have lower species compositions and so have a lower natural ‘biotic resistance’ (MacArthur & Wilson, 1967) leading to increased invader abundance, survival and fertility (Balvanera et al., 2006). Tilman (1996) backs this up by pointing out that with higher diversity individual populations are likely to fluctuate with disturbance events, whilst the community as a whole remains stable and productive. O’Dowd et al. (2003) believes that other characteristics may also be important, such as biota that do not work together providing interspecies support, where functional redundancy is low, where food webs are simple and when the amounts of introduced species are large relative to the species composition (Vitousek et al., 1996; Denslow, 2003; O’Dowd et al., 2003). In these situations even a single consuming introduced species can have dramatic direct and indirect effects on an island (Chapin et al., 1997, Fritts & Rodda, 1998; O’Dowd et al., 2003)

Extinctions on islands have also been related to a majority share of global biodiversity loss (Sax et al., 2002). So whilst it is important not to waste money on eradicating invasive which do not have negative impacts when negative impacts are seen a reduction in the resilience of the ecosystem is often a problem, as in TCI (Malumphy et al., 2012).

2.3.3 Controlling or eradicating invasives

Popular literature on IS describes three stages to invasions: arrival, establishment & spread (Williamson & Fitter, 1996). Research on controlling and eradicating IS has often been associated with damage caused to crops and plantations (Lodge et al., 2006 Schlaepfer et al., 2011), the focus of which is nearly always after the establishment and spread phases when IS are already prevalent in the environment. Eradication is often impossible so that damage reduction through control of numbers becomes the main focus (Waring & O’Hara, 2005). As such the two main methods for control researched have been:

1. Pesticide application
2. Biocontrol – the use of other species to control the invasive population, either:
   a. Introduced predatory or pathogenic agents; or
b. Natural predator or pathogen augmentation

Different pesticides have differing levels of toxicity to species they are targeted at and other non-target species in the environment, including crops (Kaur & Virk, 2012). Clarke et al. (1992) explored insecticide affects on non-target scale insects showing varying mortality, whilst an earlier study showed greater toxicity towards beneficial parasitoids than the intended insect pest targets (Clarke et al., 1988).

These interactions have been related to insect explosions (Clarke et al., 1988) where sudden resurgences are seen after spraying. They may also result from built up resistance to insecticides. In Georgia *Toumeyella parvicornis* (Cockerell) populations exploded after experiments using insecticides for seed and cone insect control were used, in such situations sustainable management strategies could be important for continued use of pesticide (Clarke et al., 1992; Kaur & Virk, 2012).

Because of the dangers associated with pesticides biocontrol agents have been used to control IS instead. Non-native species introductions often limit their negative effects. In the US, for example, the invasive California Red Scale (*Aonidiella aurantii* (Maskell)), has received extensive attention and biocontrol releases, the parasitoids *Aphytis* sp. appearing to be the most successful at keeping the pest in check (Murdoch et al., 2006).

Parasitoids are fairly host specific predators however sometimes more generalist polyphagous predators are needed and used, however, these can cause their own detrimental effects on population dynamics (Rosenheim et al., 1999; Stiling, 2004; Waring & O’Hara, 2005; Schlaepfer et al., 2011). Williamson & Fitter (1996) point out that because of their deliberate release biocontrols are more likely to become invasive over transported species.

They may have local impacts on food webs (Mochizuki et al., 2006) as with the introduced knapweed gall fly (*Urophora affinis* FrfId. and *U. quadrifasciata* (Meigen)) in Montana which failed to control Spotted knapweed (*Centaurea maculosa* Lam.) whilst providing a new food source for deer mice (*Peromyscus maniculatus*) increasing their numbers (Pearson, 2000). Or they may have a global impact, such as, the impact of the Asian harlequin ladybird (*Harmonia axyridis* (Pallas)) used as a biocontrol against aphids which has recently evolved to become a major IS worldwide (Tayeh et al., 2012).
Recovery of the endemic Caicos Pine: Invasive pest management and restoration

Therefore with the effects of foreign biocontrol agents unlikely to disappear in the environment until host species are eradicated (Pearson, 2000) and eradication proving near impossible in cases where the invasive is already established (Waring & O’Hara, 2005) their use should only be taken in extreme circumstances.

Considering this, other methods of control are necessary, such as augmenting already present natural predators in the environment including generalist feeders (New, 2002; Kontodimas et al., 2004; Stiling, 2004; Mochizuki et al., 2006). In such instances careful monitoring of the whole community to ensure success and avoid adverse affects due to altered population interactions, such as intraguild predation is required (Phoofolo & Obrzycki, 1998; Resenheim et al., 1999; Mochizuki, 2006). The effects of inbreeding and adaptation to captivity also need to be accounted for to maintain success (Heath et al. 2003; Kraaijeveld-Smit et al. 2006; Williams & Hoffman, 2009; Tayeh et al, 2012).

So far an exponential explosion of the Pine Tortoise scale can be seen in TCI suggesting that currently no predator is carrying out a controlling role. This could be due to a lack of predation or insufficient predator population sizes to be effective (Murdoch et al., 2006).

Theoretically, there will be strong selective advantage for species that exploit an abundant non-native species, thus, initial negative effects are not expected to endure indefinitely (Schlaepfer et al., 2011). It could be that there is a lag effect currently being seen, so investigation into predators already in the environment, whether they predate on the invasive and their life cycles could prove valuable to control efforts.

2.3.4 The problem of the Scale insect

The Pine Tortoise Scale (Toumeyella parvicornis (Cockerell)) insect is a member of the super family Coccoidea, one of the most transported groups in the plant trade (e.g. 89% of Pest into the UK) (Miller & Miller 2003; Smith et al. 2007; Malumphy, 2008; Malumphy et al., 2012) Adult females are larviform and neotenic whereas the males are small, winged and mobile. The life cycles of males and females are slightly different: the females go through two or three nymphal instar stages before adulthood and the males go through two before two non-feeding stages called the pupa and prepupa phases. The first stage is called a “crawler” and is the main dispersal stage because the rest are sedentary.

Crawlers usually hatch in late June to early July on a yearly basis; however, in TCI it is believed that the yearly cycle may be disrupted so that multiple generations may breed per year unrestrained by the climatic cycling (Hamilton, pers. comms). Hence, there may be all

Alex Hudson
stages of development found at any one time making any control more difficult because the crawler is the natural best stage to attack, when the insect’s defences are weakest. It has been suggested that dispersal of crawlers could be by wind, in the hair of mammals or in the plumage of birds (Greathead, 1997; Malumphy, 2012)

Native to the nearctic region, from Mexico to southern central Canada *T. parvicornis* (Cockerell) feeds exclusively on Pine (*Pinus*) species (Clarke et al. 1992; Ben-Dov 2012). It is considered a major pest in the US because infestation leads to reduced leaf production causing chlorotic spotting, distortion of growing tips, leaf drop, loss of vigour, stunted growth and mortality of trees (Newbery, 1980; Miller & Miller, 2003; Malumphy *et al.* 2012). Newbury (1980) noted greater resilience in thicker leaves due to extra water content, originally noticed in experiments on plants in salt spray zones where reduced infestation levels were suggested because of either changes in anatomy deterring stylet insertion or because osmotic potential of the phloem sap became too great (Newbery, 1980). This is backed up by observations of scale reduction in nurseries where watering is regular. It follows that in an arid climate like the TCI water deficit could play a valuable role in insect spread.

It is usually controlled by natural enemies at the tree level (Murdoch *et al.*, 2006). Generalist predator coccinellids consume young scales and eggs under the mature females including *Brachycantha ursine* (Fabr.) and *Hyperaspis congressis* Watson amongst others (Araujo-Siqueira & Almeida 2006; Michaud 2001; Stuart *et al.* 2002; Ben-Dov 2012). Different life stages of coccinellids have been shown to predate different quantities of prey making them useful year round biocontrol agents (Lucas *et al.*, 2004; Kaur & Virk, 2012; Rosas-Garcia *et al.*, 2009). In TCI *Cycloneda sanguinea* L. has been noted as more prevalent among *T. Parvicornis* (Cockerell) populations and could predate it, although not confirmed (Clarke *et al.*, 1992; Malumphy *et al.*, 2012).

Spiders also are often seen cohabitating with adult scale insects and so equally may prey on crawlers (Clarke *et al.*, 1992). The larvae of the pyralid moth (*Laetilia coccidivora*) significantly reduce heavy scale populations and lacewings have been noted as natural enemies of scale insects (Papaek *et al.*, 1995; New, 2002; Ben-Dov 2012).

Perhaps most promising though are Chalcidoïd parasitoids which have been recorded attacking the scale, including the aphelinids *Aphytis sp.*, some *Coccophagus* sp., and the encyrtid *Microterys fuscicornis* Howard. (Ben-Dov 2012). These attack all stages of scale

Alex Hudson
development, laying eggs on some and feeding directly on those which cannot be parasitized (Murdoch et al., 2006). Successful use has been seen in the US, where the California Red Scale (Aonidiella aurantii (Maskell)) is controlled by Encarsia perniciosi (Tower) and Aphytis melinus DeBach, estimated to keep the insect at numbers 200 times less than they would be (Borer, 2002).

Fire prescriptions are designed to consume thinning residues and forest floor fuels with minimal impact on retained trees (Moore et al., 1999; O’Brien et al., 2008). Restoration of ecosystem structure and reintroduction of fire are necessary for restoring rates of decomposition, nutrient cycling and net primary production to more natural, predisruptive levels where the ‘facilitation model’ of succession seems to have been in occurrence (Connell and Slatyer, 1977; O’Brien et al, 2008). Fire ecology is described in more detail in Green (2011) and the accompanying paper to this one Mark (2012). Of note, the Caicos pine has evolved to have fire tolerant characteristics, such as the dropping and re-flushing of scorched needles (O’Brien et al., 2008). With scale insect concentrations highest on these needles, combined with their sedentary nature, it is expected that this would reduce the levels of infection on trees with the direct fire affects killing them further.

2.3.5 Restoration Ecology
Ecological diversity is dependent on the ability of populations to evolve to adapt to new environments as they develop (Bedi, 1991). Human actions are swiftly changing natural systems and environments (Davis et al., 2011). This causes a threat to biological diversity through losses of evolutionary habitats without the necessary time for the adaptation of new ones (Moore et al., 1999)

Ecological restoration is seen as a “means of sustaining the life on Earth and re-establishing an ecologically healthy relationship between nature and culture” (SERI, 2011). The goal is to facilitate the return of natural forest elements by natural succession, with increasing attention to providing goods and services for humans (Harrod et al., 1999; Ruiz-Jaén & Aide, 2005). This makes it a long term strategy often needing investment periods on the scale of tree life cycles in order to achieve complete success.
Allen et al. (2002) outline 16 ecological principles for ecological restoration, which are important to consider, although not all apply to every situation. Three main questions seem to be formulated when thinking about ecological restoration in this way:

1. What constitutes a natural state and processes?
2. What are the appropriate reference conditions and variables to measure?
3. What treatments are best?

Often pre-event conditions are chosen as the natural state, processes, and reference conditions (i.e. pre the human invoked damage), paying attention to stand structure and pattern in forestry restoration (Dobson et al., 1997; Higgs, 1997; Moore et al., 1999). Whilst this information may provide a useful reference for improving long term planting success, because of changes conditions due to climate change this may prove too inflexible as an approach (Harris et al., 2006; Davis et al., 2011).

Instead a combined approach with the goal of maintaining ecosystem processes, vegetation structure and species diversity, with monitoring of affects on these, will give greater management flexibility based on success and failures of actions (Ruiz-Jaén & Aide, 2005). Schlaepfer et al. (2011) believe that looking toward the future instead of the past when setting benchmarks and devising strategies is a more positive approach, especially with the additions of non-natives, which, if non damaging, could be incorporated into conservation strategies.

With this approach success is not judged against a historical view of the ecosystem, but on whether the techniques have set the ecosystem on a trajectory that will lead to “recovery of self-sustaining ecosystem structure and function” (Bradshaw, 1984; Moore et al., 1999; Ruiz-Jaen & Aide, 2005). In the case of a changing world it may be necessary to include an addition to this “a new self-sustaining ecosystem structure and function”

Within forest systems the key problem may either be the loss of natural succession, possibly because of conversion to plantations, leading to increased tree densities of even age structure and spacing, creating a loss of habitat heterogeneity and tree species (Eckehard et al., 2008). In some cases longer-rotation plantations, which conservation focussed management may lead to, have little difference to managed natural forests (Keenan et al. 1997; Suzuki and Olson 2008; Eckehard et al, 2008). In other instances return of natural succession processes are required (Connell and Slatyer, 1977). In

Alex Hudson
overpopulated forest habitats this may require the re-addition of lost stand level management processes, such as thinning, weed control and burning, amongst other methods (Cummings & Reid, 2008; Eckehard et al., 2008).

Many of these techniques are relevant to overstocked ecosystems (Harrod et al., 1999; Moore et al., 1999) but not to situations where trees have been lost or reduced in number and the rest of the ecosystem changed or degraded. In these situations restoration needs to be carried out as part of an integrated approach of maintaining the current wild trees and using ex situ specimens to supplement wild populations where necessary and to re-establish new populations in the wild (Oldfield, 2009. The FAO (2006) recommends baseline surveys as being important in monitoring the impact of plantations.

Replacement of natural tree species with other similar species has been suggested in some situations, however this is inappropriate in many cases because natural forests usually offer superior habitat for native forest species (Du Bus de Warnaffe and Deconchat 2008; Eckehard et al., 2008). Therefore the use of replacement tree species should only be considered as a result of extirpation or extinction events.

The habitability of the forest being recreated to native species should also be an important consideration when deciding on planting regimes, with spatial and temporal patterns needing to be as random and as little like a plantation as possible (Hill et al., 1995; Halaj et al., 2001; Winder et al., 2001; Allen et al., 2002; Ruiz-Jaén & Aide, 2005). This would be improved by incorporating natural regeneration by seedlings from mature trees into restoration management designs and plans.

The type of environment being planted into has a great deal of affect on restoration projects, for example, in yearly drought conditions trees like conifers can be difficult to establish (Kazantseva et al., 2009). Increased water stress means reduced cambial activity, wood formation, and ultimately reduced growth (Dawson, 1993; Camarero et al., 2010; de Luis et al., 2009, de Luis et al., 2011) and planted tree survivorship. This can be countered using management techniques like irrigation which can maintain cambial activity and cell differentiation during the dry months affecting the vegetation structure produced (de Luis, 2011; Rossatto et al., 2012).

Reduced survivorship and growth have also been noted for nursery grown plants when planted back into the wild based on the conditions within the nursery (Bedi, 1991;
Kazantseva et al., 2009; Rossatto et al., 2012). Mycorrhizal development is important to survival because plants are able to take advantage of more water locked away in the soil, leading to less fertiliser and watering requirements (Garbaye, 2000; Hobbie & Colpaert, 2004; Kazantseva et al., 2009). Nursery workers can affect mycorrhizal development through varying factors, such as inoculation, fertiliser, pH, soil moisture content, development temperature and aeration, leading to plasticity of plant responses (Reid et al., 1983; Kazantseva et al., 2009 Bedi, 1991; Campbell et al., 2003; Hobbie & Colpaert, 2004; Hobbie et al., 2008).
3. Methods
In the field data were recorded directly into ArcPad (ESRI Version 7.0) using a handheld Trimble JUNO PDA (Trimble, 2012) with integrated Global Positioning Satellite (GPS). All statistical analysis was carried out using RStudio v. 0.96.330 (RStudio, 2012). Data were managed and edited using Botanical Research And Herbarium Management System (BRAHMS Version 7). For all statistical tests the uncertainty level was set at 5% likelihood of a type I error.

3.1 Insect transects
Insect transects were carried out on: North Caicos on 24th May, 09th June, 13th June, 16th June; Middle Caicos on 2d June, 4th June, 14th June, 15th June, 18th June, 25th June, ; and Pine Cay on 19th June, 20th June, 27th June 2012 and 28th June 2012.

Starting points for each transect were chosen using one of three methods.

1. **Edge selection** - A random direction (see randomisation method in appendix 7.1) was selected when standing in the middle of the edge of a permanent monitoring plot or on entering an area of open vegetation. 50 metres were paced in that direction to the start point.

2. **Random map point** - Random points were placed on ArcPad map avoiding crossing with other transects from previous years work on pine density (see Green, 2011 and Mark, 2012). The GPS was then used to find these points;

3. **Parallel** - Many transects were carried out in parallel to others by heading 200 metres (with the exception of the second transect in Middle Caicos which was set at 50m) perpendicular to the usual transect bearing i.e. 190 degrees.

The bearing for the majority of transects was decided randomly before investigations began using the milliseconds on a stopwatch set to directions (see table 3.1 and randomisation methodology for full account in appendix 7.1). Each transect had five points investigated along it at 50m intervals.

<table>
<thead>
<tr>
<th>Direction</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>140</th>
<th>160</th>
<th>180</th>
<th>200</th>
<th>220</th>
<th>240</th>
<th>260</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milliseconds</td>
<td>0-9</td>
<td>10-19</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
<td>90-99</td>
</tr>
</tbody>
</table>

Table 3.1: Possible options for random selection of transect direction. 100 degrees was chosen

Alex Hudson
Distances between transects and transect points were measured out by pacing 50 steps in the correct direction on a compass and then checking position using the GPS on ArcPad (although with difficulty travelling through certain areas of bush and inaccuracy of the GPS it was accepted this would not always be exact positioning).

Transects had to remain inside pineyard boundaries as defined on the ArcPad maps so when edges were reached transects direction was changed by 90 degrees heading back into the pineyard. At the same time using the same transect points Mark (2012) recorded tree density of live and dead trees as well as carrying out a vegetation survey in the plots.

At each transect point a 10m x 10m plot was divided into four quarters (see figure 3.1) and the largest pine in each investigated for possible scale predators. Seedlings were not investigated because of a lack of branches. Two branches were selected randomly and were hit five times with a cloth held underneath to catch falling insects. The number of insects was recorded with scale infestation levels of the trees and the plot using the scale shown in table 3.2. Plants were also investigated for lacewing eggs by sight, found on the ends of thin threads. These were recorded as presence/absence.

At the end of each trees investigated the cloth was emptied onto the ground so that no insects would be transported between pine trees.
Recovery of the endemic Caicos Pine: Invasive pest management and restoration

Table 3.2: List of pre fire data recorded and the possible recorded values:

<table>
<thead>
<tr>
<th>Field</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shading</td>
<td>0 to 5</td>
</tr>
<tr>
<td>Cassytha filiformis parasitisation</td>
<td>Presence/absence</td>
</tr>
<tr>
<td>Angadenia berteroi parasitisation</td>
<td>Presence/absence</td>
</tr>
<tr>
<td>Yellowing needles</td>
<td>Presence/absence</td>
</tr>
<tr>
<td>Brown branch tips</td>
<td>Presence/absence</td>
</tr>
<tr>
<td>Strobili present</td>
<td>Male, female, both or none</td>
</tr>
<tr>
<td>Cones present</td>
<td>None, 1\textsuperscript{st} year, 2\textsuperscript{nd} year, old cones or mixtures of the previous three.</td>
</tr>
<tr>
<td>Photo</td>
<td>.jpg file created</td>
</tr>
<tr>
<td>Scale infestation</td>
<td>0 to 5 (0 = no infestation, 5 = heavy infestation)</td>
</tr>
<tr>
<td>Canopy loss</td>
<td>0 to 5</td>
</tr>
<tr>
<td>Mould cover</td>
<td>Percentage in 5% intervals</td>
</tr>
<tr>
<td>Fire damage</td>
<td>Yes or no</td>
</tr>
<tr>
<td>Fire recent</td>
<td>Yes or no</td>
</tr>
<tr>
<td>Ladybirds</td>
<td>Presence/absence</td>
</tr>
<tr>
<td>Wasps</td>
<td>Presence/absence</td>
</tr>
<tr>
<td>Height – to tip of the tallest candle growth not the surrounding needles</td>
<td>Metres</td>
</tr>
<tr>
<td>DBH - measured at one inch above ground level if not possible at breast height</td>
<td>Centimetres</td>
</tr>
</tbody>
</table>

### 3.1.1 Data analysis

Some data used in the analysis, such as the number of trees in a plot were taken from data collected by Jennifer Mark in the accompanying thesis project (Mark, 2012). Transect data was compiled, combining numbers of insects on trees within plots to a single mean value for the plot, based on the number of trees investigated, to avoid pseudoreplication. Before tests, abundance data was log transformed because it did not fit a normal distribution. Single factor Analysis of Variance (ANOVA) was used to compare plots across the three islands, scale infestation level and disturbance type. A regression analysis was carried out on tree numbers in plots, canopy height and canopy percentage cover.

The ANOVA relating scale infestation and lacewing larvae abundance was further reduced to include only Middle Caicos data because of island affects on insect numbers. Orthogonal contrasts were carried out to discover between which infestation levels the main significant
difference was being seen. North Caicos was not included either because of the lack of plots investigated with trees in leading to no plots with a scale infestation of 5 introducing uncertainty into any results investigating the affects of a scale infestation level of 5.

The Lacewing egg data, as a binomial factor, was treated to different statistical tests. Fisher’s exact test was used to compare the difference between the means across the three islands, at different scale infestation levels and on different disturbance types. Wilcoxon’s rank-sum test was used on the tree plot numbers, canopy height and canopy percentage cover. A Generalised Linear Model (GLM) was then fitted to the most significant variables using step wise deletion methods (Crawley, 2007) to find the simplest model that still adequately fitted the data.

### 3.2 Restoration plot set up

Plot set up was carried out on the 17th and 18th May, planting was carried out on the 18th, 22nd, 23rd and 25th May 2012. Tree enclosures were made on 23rd and 25th May. Follow up assessment was carried out on 7th June and 29th June.

Three 20m x 20m plots were set up in a row North to South on Pine Cay with a 2m wide walkway round the edge to reduce soil compaction from walking through the plots repeatedly. Each was subdivided into 25 4m x 4m plots using string (see figure 3.2) with planting positions randomly generated randomly in arcMAP 9.3 within these. Each position was assessed to make sure it also fulfilled the following criteria in the field:

1. Each 4m x 4m sub plot had only one planted tree from the Kew nursery.
2. It was greater than 2m to the nearest other pine tree (planted or “natural”)
3. The soil planted on was a pot height depth so that planting would be successful.

(For more details on transport and planting methodology see appendix 7.2)
Figure 3.2: The set up of each of three restoration plots. Two other plots are to the North and South.

At the edge of the first (south side) and second plots (north side) there was one large mature pine with old and new cones. In total plot one had 26 pine trees of all sizes already found within it, plot two had seven and plot three had zero. Pines were classified into one of three categories based on size (see table 3.3). These were assessed using the criteria outline in table 3.2 and their position was recorded using the GPS on ArcPad. For trees too large to measure the height with a tape measure a clinometer was used (see appendix 7.3 for use).

Table 3.3: Categories and limits for pine plant classification.

<table>
<thead>
<tr>
<th>Category</th>
<th>Height limit</th>
<th>Diameter Breast Height (DBH) limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seedling</td>
<td>( \leq 0.30\text{m} )</td>
<td>-</td>
</tr>
<tr>
<td>Sapling</td>
<td>( &gt;0.30\text{m} )</td>
<td>( \leq 4\text{cm} )</td>
</tr>
<tr>
<td>Tree</td>
<td>( &gt;0.30\text{m} )</td>
<td>( &gt;4\text{cm} )</td>
</tr>
</tbody>
</table>
Within each plot one of the saplings and two seedlings were protected with a chicken wire mesh fence to protect the plants from birds. A further sapling and two seedlings were protected further with chicken wire and fly screen attached to the inside, to protect the plants from wind dispersed scale (for cage building methods see appendix 7.4). Plant choice was random based on the grid of planting areas within plots. The milliseconds on a stopwatch chose which plot in the row and then column would be picked using the values in table 3.4.

Table 3.4: Choice selections for deciding which planted pines to put cages around. X was from North to South and Y was from East to West

<table>
<thead>
<tr>
<th>Milliseconds</th>
<th>0-19</th>
<th>20-39</th>
<th>40-59</th>
<th>60-79</th>
<th>80-99</th>
</tr>
</thead>
<tbody>
<tr>
<td>X / Y grid number</td>
<td>1st</td>
<td>2nd</td>
<td>3rd</td>
<td>4th</td>
<td>5th</td>
</tr>
</tbody>
</table>

If a planted tree with cage was already found within the row or column being investigated it was removed from the possible selection odds and the millisecond ranges changed accordingly.

Watering was continued on follow up visits and assessments to the Island on 28th May, 19th June and 29th June. After that time the rainy season is expected to provide a lot of rain to keep the plants from desiccating. The local government members of the CRPR will continue watering as and when is necessary during dry periods. In addition to this make shift slow drip irrigation was made using up turned water bottles (c. 1L-4L volume) with holes in the lids. These were dug into holes in the soil next to trees slowly releasing water into the soil surrounding the root balls. During these follow up trips records of mortality and the cause of mortality were made if possible.

### 3.2.1 Data analysis

Statistical analysis was carried out to identify any difference in morphological characteristics of pines between the plots to provide a baseline for future monitoring of affects. A Fisher’s exact test was also carried out on the Needle fascicle number data. Single factor ANOVAs were applied to the height, diameter at breast height (DBH), plant maximum and minimum needle lengths, and plant maximum and minimum sheath lengths comparing the variances in these across the three restoration plots. For the height and DBH data a normal Q-Q plot suggested the assumption of normality of errors was not being met, therefore the data were separated into saplings and seedlings because these two
categorisations were chosen to delineate the heights of plants and because a certain number of each class was deliberately planted. The ANOVAs were run again on these, which increased the normal Q-Q plot fit in all cases making the new ANOVAs more reliable.

**3.3 Experiments on scale reduction by fire management**

The three fire plots were situated on Middle Caicos within the area of the old pine yard near Conch Bar and were set out by project and governmental staff as shown in figure 3.3. Ground cover was cleared to a metre around pines within the non-control plots.

![Figure 3.3: Fire plot set up A) the two plots with clearing around pines (Total area burnt = 4330.13m²); and B) The control plot without any manual clearing. All plots had a 2m wide fire break 2m cleared of vegetation so that fire would not cross.](image)

Pre fire measurements were taken on the 8th and the morning of the 9th May 2012. At each non-control plot one side was selected at random (see appendix 7.1 for randomisation method) and reference marker left at the mid-point. This was used to place transect points starting at the opposing corner as in figure 3.3(a). The control was laid out with three points in a row with two extra situated randomly because of the smaller size of the plot (see figure 3.3(b)). Points were marked with metal number tags attached to rocks.

At each point the point centre quarter method was used to divide the circular area around it into four quadrants at a circumference of 10m. Within each quadrant the nearest seedling, sapling and tree (dead or alive) were recorded and measured using the methods outlined in the coupling thesis to this one (see Mark, 2012).
Recovery of the endemic Caicos Pine: Invasive pest management and restoration

For this project one of the quadrants was selected randomly (see appendix 7.1 for random selection methodology) and the nearest seedling and sapling tagged using fire proof copper tags before assessing. Assessment criteria were taken from previous investigation (See Earle-Mundin, 2010; Green, 2011) and can be seen in tables 3.2. NOTE: The pre fire data for plot two were collected by Martin Hamilton and Marcella Corcoran.

Three fascicles of pine needles were also collected avoiding any from this year’s new growth. Further morphological and scale insect data was recorded, measuring: the length of the largest and smallest needles, the sheath lengths, and counting the numbers of adult female pine tortoise scales on each.

When no saplings or seedlings could be found within a quadrant then the other quadrants were searched systematically in a clockwise direction until one was found and tagged. At points where no seedlings could be found the next nearest sapling was selected, tagged and assessed instead.

After the fire experiments had been completed the tagged trees were re-assessed including fascicle collection three further times on 13th and 15th May, then on 29th, 30th and 31st May 2012 and finally on the 1st, 2nd and 3rd July 2012. Re-assessment included additional fire measurements outlined in table 3.5. These were decided after initial analysis of the burning affects on plot trees, deciding that percentage cover would be the best way to record extent of burning, with presence of apical green growth and frozen needles as good identifiers of differences between plants with similar scorch percentage cover.

Table 3.5: List of post fire data recorded and the recorded values (in addition to those outlined in table 3):

<table>
<thead>
<tr>
<th>Field</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scorch level</td>
<td>Percentage in 5% intervals</td>
</tr>
<tr>
<td>Frozen needles</td>
<td>Presence/absence</td>
</tr>
<tr>
<td>Apical green growth</td>
<td>Presence/absence</td>
</tr>
</tbody>
</table>

More trees were found, tagged and investigated to increase the power of analysis in post fire changes. This included tagging of mature trees (two within plot 1, four in plot 2 and none in the control) with assessment of these aided by the use of a clinometers and binoculars. A stratified random sampling method was employed to choose numbers of scorched and unscorched plants so that equal numbers of each type and equal numbers of seedlings and saplings were selected classifying the cut off for “scorched” at 50%.

Alex Hudson
Sampling was carried out by randomly selecting one of the two sides not used in creating the initial transects by tossing a coin for heads or tails. A direction was selected at random (see appendix 7.1) and followed until a pine that fitted the selection criteria was found. The direction was continued until either all pines had been found or a plot edge was reached. If the plot edge was reached a random direction was selected again.

3.3.1 Data analysis

Fisher’s exact tests were used to highlight any dependence on scorch and changes in scale infestation level by dividing the data into two sets “scorched” and “unscorched” and the division percentage being changed with each test.
4. Results

4.1 Insect data
Within the insect transect experiment a difference was seen in the number of plots with trees in and so could be investigated for insect presence across islands. This is outlined in table 4.1, reflecting a general lack of Caicos pine found in the pineyard on North Caicos.

Table 4.1: The total number of 10m x 10m plots investigated on each island which had trees within them.

<table>
<thead>
<tr>
<th>Island</th>
<th>Pine Cay</th>
<th>Middle Caicos</th>
<th>North Caicos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of plots with trees</td>
<td>23</td>
<td>34</td>
<td>9</td>
</tr>
</tbody>
</table>

4.1.1 Lacewing eggs
Figure 4.1 shows the effects of the number of pine trees in plots positively affecting lacewing egg presence (Top left). When separating up the islands, the relationship becomes less distinct, especially on North Caicos and Pine Cay (top right and bottom right). This suggests the difference may be due to island affect.

Figure 4.1: Plots of the variation in total numbers of pine trees found in plots with and without lacewing eggs present. The top left plot shows the total effect across all islands, the remaining plots show the variation seen on each of the islands. The first plot (All islands) has Tukey notches applied to give a visual impression of the significance of the difference of the means, since the notches do not overlap. NOTE: Notches are not displayed on the individual island boxplots because they extended over the edges of either the 25th or 75th percentile ranges representing a likely invalidity of the test.
Figure 4.2 shows the significant differences of the median values and variation between canopy heights with lacewing egg presence/absence. There is consistency across the islands suggesting the affects are a result of differences between the islands and so that greater canopy height has a negative effect on the presence of lacewing eggs on pine trees.

Figure 4.2: Plots of variation in canopy height variances with and without lacewing eggs. In all cases the median values are outside the interquartile ranges, suggesting some significant differences. The plots also show a lot of skews in the data, which varies with island.

The results of the statistical analysis on lacewing egg presence are displayed in table 4.2. For the number of trees in plots and canopy heights the null hypothesis that there is no difference between the mean of plots with and without lacewing egg presence is rejected. The Fisher’s exact test for the p-value for the islands and scale infestation variables are also significant so the null hypothesis that the variables are independent is rejected suggesting island and infestation levels investigated affects whether lacewing eggs are likely to be found. The other two variables show no effects on presence of lacewing eggs in plots.
Table 4.2: The statistical tests carried out between lacewing egg presence as the response variable and the other explanatory variables: Islands; Tree numbers; Scale infestation; Canopy height; % cover; Disturbance. The p-values represent the likelihood of rejecting the null hypothesis. One star (“*”) denotes a significance value below this, two stars (“**”) denotes a significance value below 1% and three stars (“***”) denotes a significance value below 0.1%.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Statistical Test</th>
<th>Degrees of freedom</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Islands</td>
<td>Fishers exact test</td>
<td>2</td>
<td>9.223e-09 ***</td>
</tr>
<tr>
<td>Tree number in plots</td>
<td>Wilcoxon’s rank-sum test</td>
<td></td>
<td>0.001485 ***</td>
</tr>
<tr>
<td>Scale infestation</td>
<td>Fisher’s exact test</td>
<td>5</td>
<td>0.01851*</td>
</tr>
<tr>
<td>Canopy height</td>
<td>Wilcoxon’s rank-sum test</td>
<td></td>
<td>1.578e-05***</td>
</tr>
<tr>
<td>Canopy cover (%)</td>
<td>Wilcoxon’s rank-sum test</td>
<td></td>
<td>0.2832</td>
</tr>
<tr>
<td>Disturbance</td>
<td>Fisher’s exact test</td>
<td>2</td>
<td>0.09521</td>
</tr>
</tbody>
</table>

4.1.1 Generalised Linear Model

Table 4.3 shows the results of the GLM being run three times. The third model implies canopy height and island are the best variables to explain lacewing egg presence because the Akaike Information Criteria (AIC) value is lowest. The first model has the lowest residual deviance, however, suggesting less unexplained variation so that island, pine density and the interaction between the total number of pines and the canopy height explain the presence of lacewing eggs best. Within the first model the main island difference was between Pine Cay and Middle Caicos producing a p-value of 0.000511, whilst the p-value for North Caicos was 0.993024 and so not significantly different. Infestation level never features in the final simplified model, suggesting it is not a good variable at indicating lacewing egg presence.
Recovery of the endemic Caicos Pine: Invasive pest management and restoration

Table 4.3: Three possible models reached after running step deletions from saturated generalised linear models with their residual deviances and AIC values to show their level of fitness to the data.

<table>
<thead>
<tr>
<th>Model</th>
<th>Degrees of freedom for residual deviance</th>
<th>Residual deviance</th>
<th>Degree of freedom on AIC</th>
<th>AIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. lacewingeggPlotPresence ~ majorarea + totalpine + totalpine:canopym</td>
<td>61</td>
<td>39.476</td>
<td>5</td>
<td>49.47623</td>
</tr>
<tr>
<td>2. lacewingeggPlotPresence ~ canopym + totalpine</td>
<td>63</td>
<td>63.144</td>
<td>3</td>
<td>69.144</td>
</tr>
<tr>
<td>3. lacewingeggPlotPresence ~ canopym + majorarea</td>
<td>62</td>
<td>40.854</td>
<td>4</td>
<td>48.854</td>
</tr>
</tbody>
</table>

4.1.2 Spiders

Figure 4.3 shows the difference in variation across islands (left plot) and with infestation levels (right plot). The Tukey notches highlight a significant different in variation between Pine Cay and the other two Islands and high infestation with no infestation.

Figure 4.3: The left plot shows the variation in median and range of values of mean plot spider numbers across the three islands. The right plot shows the variation in the mean plot spider numbers with different infestation levels. Recordings of 1 and 2 have been joined together to a single low infestation level and 3, 4 and 5 have been joined to form a single high infestation level. Notches have been added to highlight any significant differences.

Figure 4.4 shows a generally positive linear relationship between spider numbers and tree density. This is apparent across all islands, except Pine Cay where numbers are always low. The relationship is strongest on North Caicos where there were also least plots investigated.

Alex Hudson
Recovery of the endemic Caicos Pine: Invasive pest management and restoration

Figure 4.4: Linear regressions for spider abundance changes with change in number of trees in plots. Island data points and regression lines are separated by colour.

The results of the statistical tests carried out on the spider abundance data are printed in table 4.4 There were significant differences to be explained for variation across islands and scale infestation levels especially when combined to make three levels: no scale, low scale and high scale infestation. For number of trees in plots the regression $r^2$ value shows that roughly 6% of the variation in spider abundance is explained by the variation in number of trees in plots. The p=value significance points to regression slope not equaling zero.
Recovery of the endemic Caicos Pine: Invasive pest management and restoration

Table 4.4: The statistical tests carried out on the spider abundance and other explanatory variables with the p-values produced. (Bracket scale infestation is when the two lowest scale infestation levels (not including complete absence of scale) and the three highest is conjoined). Insect count data was log transformed before analysis in order to normalise the distribution of the insect counts. One star (“*”) denotes a significance value below this, two stars (“**”) denotes a significance value below 1% and three stars (“***”) denotes a significance value below 0.1%.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Test</th>
<th>Degrees of freedom</th>
<th>p-value</th>
<th>Multiple r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Islands</td>
<td>ANOVA</td>
<td>2 and 63</td>
<td>0.005207**</td>
<td>0.1537</td>
</tr>
<tr>
<td>Tree number in plots</td>
<td>Linear regression</td>
<td>1 and 64</td>
<td>0.04835*</td>
<td>0.05953</td>
</tr>
<tr>
<td>Scale infestation</td>
<td>ANOVA</td>
<td>5 and 60</td>
<td>0.09705.</td>
<td>0.1407</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2 and 63)</td>
<td>(0.02575*)</td>
<td>(0.1097)</td>
</tr>
<tr>
<td>Canopy height</td>
<td>Linear regression</td>
<td>1 and 64</td>
<td>0.587</td>
<td>0.004641</td>
</tr>
<tr>
<td>Canopy cover (%)</td>
<td>Linear regression</td>
<td>1 and 64</td>
<td>0.243</td>
<td>0.02128</td>
</tr>
<tr>
<td>Disturbance</td>
<td>ANOVA</td>
<td>2 and 63</td>
<td>0.184</td>
<td>0.05233</td>
</tr>
</tbody>
</table>

4.1.3 Lacewing larvae

Figure 4.5 demonstrates the variation in lacewing larvae abundance between islands and infestation level. Across islands a difference can be seen between Pine Cay and the other islands. Scale infestation variance increases with increasing scale infestation levels. At the highest infestation level the biggest, most significant increase was seen, suggesting a positive relationship between lacewing larvae numbers and increased presence of scale. The lack of any lacewing larvae on lower infestation levels supports this.

Figure 4.5: The left plot shows the variation in mean number of lacewing larvae found on plots on the three islands. The right plot shows the mean number of lacewing larvae found on plots with various scale infestation level recordings.
The results of statistical tests on the lacewing larvae abundances are shown in table 4.5. There were significant differences to be explained for variation across islands and scale infestation. The significance of variation in scale was increased by joining the two lowest levels (1 and 2) of scale infestation together to make five levels in total: no scale, low scale, 3, 4 and 5.

Table 4.5: The statistical tests carried out on the lacewing larvae abundance response variable and the other explanatory variables with the p-values produced. (Bracket scale infestation is when the two lowest scale infestation levels (not including scale absence) are joined together). One star (“*”) denotes a significance value below this, two stars (“**”) denotes a significance value below 1% and three stars (“***”) denotes a significance value below 0.1%.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Test</th>
<th>Degrees of freedom</th>
<th>p-value</th>
<th>Multiple $r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Islands</td>
<td>ANOVA</td>
<td>2 and 63</td>
<td>0.007707**</td>
<td>0.1431</td>
</tr>
<tr>
<td>Tree number in plots</td>
<td>Regression</td>
<td>1 and 64</td>
<td>0.3609</td>
<td>0.01306</td>
</tr>
<tr>
<td>Scale infestation</td>
<td>ANOVA</td>
<td>5 and 60</td>
<td>0.00467**</td>
<td>0.2406</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4 and 61)</td>
<td>(0.002013**)</td>
<td>(0.2388)</td>
</tr>
<tr>
<td>Canopy height</td>
<td>Regression</td>
<td>1 and 64</td>
<td>0.2904</td>
<td>0.01745</td>
</tr>
<tr>
<td>Canopy cover (%)</td>
<td>Regression</td>
<td>1 and 64</td>
<td>0.5637</td>
<td>0.005236</td>
</tr>
<tr>
<td>Disturbance</td>
<td>ANOVA</td>
<td>2 and 63</td>
<td>0.4799</td>
<td>0.02304</td>
</tr>
</tbody>
</table>

A further ANOVA analysis just using the data from Middle Caicos produced even stronger evidence for a relationship between the variation in abundance of lacewing larvae and increasing infestation level. The p-value produced was 0.001829** and so of greater significance than when scale infestation levels were combined using all the islands data.

Orthogonal Contrasts results are shown in table 4.6. This shows three significant differences between scale infestation levels:

1. Between scale infestation levels of 1 and 2 compared with 3, 4 and 5.
2. Between scale infestation level 3 compared with 4 and 5.
3. Between scale infestation levels of 4 and 5.
Recovery of the endemic Caicos Pine: Invasive pest management and restoration

Table 4.6: The contrasts results for Middle Caicos data set \( k = 6 \) (the number of scale infestation factor levels) in this case the number of orthogonal contrasts possible \( = k - 1 = 6-1 = 5 \):

<table>
<thead>
<tr>
<th>Contrast investigated</th>
<th>Standard error</th>
<th>T value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 vs {1, 2, 3, 4, 5}</td>
<td>4.233e-02</td>
<td>-0.840</td>
<td>0.40816</td>
</tr>
<tr>
<td>{1,2} vs {3,4,5}</td>
<td>5.837e-02</td>
<td>-2.436</td>
<td>0.02147*</td>
</tr>
<tr>
<td>1 vs 2</td>
<td>1.376e-01</td>
<td>0.000</td>
<td>1.00000</td>
</tr>
<tr>
<td>3 vs {4,5}</td>
<td>3.234e-02</td>
<td>3.511</td>
<td>0.00153**</td>
</tr>
<tr>
<td>4 vs 5</td>
<td>6.248e-02</td>
<td>3.059</td>
<td>0.00486**</td>
</tr>
</tbody>
</table>

Orthogonal polynomial contrast provides evidence for only retaining a linear term for the explanatory power of the model. This was highlighted in a contrast carried out with the inclusion of North Caicos which produced the results seen in table 4.7. The fifth contrast drastically changed to become insignificant whereas the others had p-values raised slightly, making them less significant with the exception of the fourth contrast, which lowered the p-value by 0.00001.

Table 4.7: The contrasts results for data minus Pine Cay \( k = 6 \) (the number of scale infestation factor levels) in this case the number of orthogonal contrasts possible \( = k - 1 = 6-1 = 5 \). One star (“*”) denotes a significance value below this, two stars (“**”) denotes a significance value below 1% and three stars (“***”) denotes a significance value below 0.1%.

<table>
<thead>
<tr>
<th>Contrast investigated</th>
<th>Standard error</th>
<th>T value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 vs {1, 2, 3, 4, 5}</td>
<td>5.095e-02</td>
<td>-0.623</td>
<td>0.5373</td>
</tr>
<tr>
<td>{1,2} vs {3,4,5}</td>
<td>5.443e-02</td>
<td>-2.331</td>
<td>0.0253*</td>
</tr>
<tr>
<td>1 vs 2</td>
<td>1.254e-01</td>
<td>0.000</td>
<td>1.00000</td>
</tr>
<tr>
<td>3 vs {4,5}</td>
<td>3.710e-02</td>
<td>2.546</td>
<td>0.00152**</td>
</tr>
<tr>
<td>4 vs 5</td>
<td>6.492e-02</td>
<td>1.284</td>
<td>0.2072</td>
</tr>
</tbody>
</table>
4.2 Restoration plot results

Figure 4.6 shows the variation between the plots in the height and DBH characteristics. The main difference is displayed in the middle plots, between plot 1 and the other two plots for seedling height and DBH.

![Box plots showing variation in height and DBH for different restoration plots.](image)

Figure 4.6: The variation between the plots in the height and DBH characteristics. Top plots are all data together; the outliers represent the sapling data. The data are skewed because the majority of planted trees were seedlings. The middle two graphs show variation between seedlings with plot 1 seemingly the most significantly different. The bottom two plots show a lack of variation between sapling data.

Statistical analysis carried out on the morphological characteristics of the planted trees on the three restoration plots is revealed in table 4.8. These analyses showed only a significant variance between the plots for seedling height and DBH, but not for the saplings or any other explanatory variables.
Table 4.8: The statistical tests carried to discover differences between the restoration plots planted tree morphological data differences. One star (‘*’*) denotes a significance value below this, two stars (‘***’) denotes a significance value below 1% and three stars (‘****’) denotes a significance value below 0.1%.

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Test</th>
<th>Degrees of freedom</th>
<th>p-value</th>
<th>Multiple r²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Height</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seedlings</td>
<td>ANOVA</td>
<td>2 and 50</td>
<td>0.00317**</td>
<td>0.2056</td>
</tr>
<tr>
<td>Saplings</td>
<td></td>
<td>2 and 19</td>
<td>0.9128</td>
<td>0.009556</td>
</tr>
<tr>
<td><strong>DBH base</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seedlings</td>
<td>ANOVA</td>
<td>2 and 50</td>
<td>0.002377***</td>
<td>0.2838</td>
</tr>
<tr>
<td>Saplings</td>
<td></td>
<td>2 and 19</td>
<td>0.901</td>
<td>0.01091</td>
</tr>
<tr>
<td><strong>Max needle length</strong></td>
<td>ANOVA</td>
<td>2 and 72</td>
<td>0.9675</td>
<td>0.009164</td>
</tr>
<tr>
<td><strong>Min needle length</strong></td>
<td>ANOVA</td>
<td>2 and 72</td>
<td>0.6214</td>
<td>0.01313</td>
</tr>
<tr>
<td><strong>Max sheath length</strong></td>
<td>ANOVA</td>
<td>2 and 72</td>
<td>0.0508</td>
<td>0.07945</td>
</tr>
<tr>
<td><strong>Min sheath length</strong></td>
<td>ANOVA</td>
<td>2 and 72</td>
<td>0.07038</td>
<td>0.07107</td>
</tr>
<tr>
<td><strong>Needle fascicle no.</strong></td>
<td>Fisher’s exact test</td>
<td>2</td>
<td>0.5165</td>
<td>NA</td>
</tr>
</tbody>
</table>
4.3 Fire data

4.3.1 The initial 30

Figure 4.7 of the change in mean values across the 4 time intervals shows there is no difference between the means of the total number of adults for each of the 30 pines investigated from pre to post fire.

![Graph showing mean adult scale}

Figure 4.7: The mean number of adult scale found on three collected fascicles of tagged pines before the fire and at three time intervals after the fire

4.3.2 All post fire scorched trees

Figure 4.8 shows the change in frequencies of each scale infestation level at all time intervals combined. At each time interval the number of trees counted with a scale infestation level of 0 increased indicating a continuing trend in scale infestation loss after a fire event. Scale levels of 1 and 2 remain stable, whilst scale levels of 3, 4 and 5 show a decrease in occurrences, corroborating with changes in no scale number recordings, that fire has a negative effect on scale insects. The most severe decline is in levels of 5. Scale infestation level of 3 shows a sharp increase at time interval 2 and before falling to a frequency lower than at interval 1.
Recovery of the endemic Caicos Pine: Invasive pest management and restoration

4.3.3 Most scorched trees

Figure 4.9 shows the change in frequencies for just the 38 most scorched plants. There is a sharp rise in the number of scorched trees given an infestation level of 0 and decreases at all other scale infestation levels. The two highest infestation levels show a complete decline to 0 occurrences.

Figure 4.9: Change in frequency of scale infestation levels for plants classed as “Scorched” just after the fire (i.e Scorch % judged to above 30)
4.3.4 Least scorched trees

Figure 4.10 shows the change in frequencies of scale infestation levels of the 36 least scorched plants. Scale infestation levels of 1, 3 and 4 remain fairly stable throughout. There is a sharp decrease and then increase in scale infestation levels awarded 2, matched in part by a smaller alternate increase and decrease in scale level 1. Scale of 0 also shows an increase and then decrease in frequency. Scale infestation level of 5 shows a gradual decrease throughout time intervals after the fire.

Figure 4.10: Change in scale infestation level frequency for plants classed as “Unscorched” just after the fire (i.e Scorch % judged to be below 30)

Figures 4.9 and 4.10 together highlight one similarity in scale infestation levels of 5 frequencies, but many differences across other infestation levels. This suggests that scorching from fire has a larger negative effect on scale infestation than a lack of scorching.

4.3.5 Scorch variation

The variation in number of adult scale insects found on three collected fascicles at each time investigation is shown in figure 4.11. At higher scorch percentages at all time intervals the number of scale insects recorded on fascicles is much reduced with the highest values (all values above five) seen at scorch values under 40%.
The variation and association of the scale levels with different scorch percentages is represented in figure 4.12. In most cases the variation in percentage scorch for a scale level of 0, 1, 2 or 3 is very high, spanning from 0 to 100%. Across all time intervals a scale infestation of 0 is associated with a variation in scorch percentage of 50% and above. Higher infestation levels show less variation in scorch from one time interval to the next. By the final time step high infestation levels are almost exclusively associated with scorch levels under 5-10. Across the low infestation levels a shift in the skew of the data can be seen from high scorch percentage to low. There is an increasing trend through the time intervals of scale infestation only being associated with low percentage cover of scorched needles, visualised by the change in skew and then reduction in inter quartile ranges.
Recovery of the endemic Caicos Pine: Invasive pest management and restoration

Figure 4.12: Variation in scorch percentages with different scale infestation levels. The top left plot shows all post fire data, the remaining three plots display the relationship at each time interval investigated after the fire.

Table 4.9 shows the significance values of Fisher’s exact tests. Nearly all cases show a significant difference so that the null hypothesis that scale infestation level is independent to whether or not the plant was scorched is rejected. The only contradictory evidence to this is in the initial investigation after the fire when the divide is set to the mean percentage value (44%) and above. Therefore when least scorched includes more of the trees with scorch up to 44% the relationship between scale infestation and scorch is lost.
Table 4.9: p-values from chi square and fisher’s exact tests for scale infestation data against scorch when plants are divided into two groups based on scorch percentages. One star (“*”) denotes a significance value below this, two stars (“**”) denotes a significance value below 1% and three stars (“***”) denotes a significance value below 0.1%.

<table>
<thead>
<tr>
<th>Time interval</th>
<th>Scorched/Unscorched limit percent</th>
<th>Degrees of freedom</th>
<th>Pearson’s chi square test p-value</th>
<th>Fisher’s exact test p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>5</td>
<td>1.673e-11***</td>
<td>2.931e-12***</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>5</td>
<td>2.851e-12***</td>
<td>2.126e-14***</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>5</td>
<td>1.347e-11***</td>
<td>2.79e-12***</td>
</tr>
<tr>
<td></td>
<td>Mean value</td>
<td>5</td>
<td>2.761e-11***</td>
<td>6.644e-12***</td>
</tr>
<tr>
<td></td>
<td>80%</td>
<td>5</td>
<td>8.382e-11***</td>
<td>1.671e-11***</td>
</tr>
<tr>
<td></td>
<td>First investigation post fire</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>5</td>
<td>4.905e-05***</td>
<td>6.477e-06**</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>5</td>
<td>4.991e-06***</td>
<td>1.4787e-06***</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>5</td>
<td>7.205e-05***</td>
<td>3.966e-05***</td>
</tr>
<tr>
<td></td>
<td>Mean value</td>
<td>5</td>
<td>0.0001788***</td>
<td>0.00197**</td>
</tr>
<tr>
<td></td>
<td>80%</td>
<td>5</td>
<td>0.000292***</td>
<td>0.0001526***</td>
</tr>
<tr>
<td></td>
<td>Second investigation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>5</td>
<td>0.001276**</td>
<td>0.0002212***</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>5</td>
<td>6.179e-06***</td>
<td>8.538e-07***</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>5</td>
<td>3.136e-07***</td>
<td>2.272e-08***</td>
</tr>
<tr>
<td></td>
<td>Mean value</td>
<td>5</td>
<td>3.136e-07***</td>
<td>2.272e-08***</td>
</tr>
<tr>
<td></td>
<td>80%</td>
<td>5</td>
<td>1.03e-05***</td>
<td>1.428e-06***</td>
</tr>
<tr>
<td></td>
<td>Third investigation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>5</td>
<td>0.001276**</td>
<td>0.0002212***</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>5</td>
<td>6.179e-06***</td>
<td>8.538e-07***</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>5</td>
<td>3.136e-07***</td>
<td>2.272e-08***</td>
</tr>
<tr>
<td></td>
<td>Mean value</td>
<td>5</td>
<td>3.136e-07***</td>
<td>2.272e-08***</td>
</tr>
<tr>
<td></td>
<td>80%</td>
<td>5</td>
<td>1.03e-05***</td>
<td>1.428e-06***</td>
</tr>
</tbody>
</table>
5. Discussion

5.1 Insects discovered on Caicos Pines

5.1.1 Differences across the islands
For all insect data there was a marked difference in abundances across islands, in particular between Pine Cay and the other two Islands. This could be due to the size of the island in comparison to the other two islands, and so proximity to the sea on all sides, leading to greater salt influences (Newbury, 1980). There is a difference in vegetation type which reflects this. The Island is also run by the Meridian Club which manages it differently to the other pineyards (which receive relatively little) which could also account for changes in insect abundances.

5.1.2 Predator association with tree density
An association with increased tree density and height has been identified for spiders and lacewing egg presence. A similar negative association between reduced canopy density and invertebrate numbers has been seen in other forest communities (Hill et al., 1995).
Arboreal spiders have been shown to be affected by both canopy and needle density reduction on trees (Halaj et al., 2000). Therefore the reduction in trees seen as a result of the scale insect infestation could help explain why predator numbers have not shown an increase in relation to the new food availability. This could account for the extended lag in the population boom of the predators, and provide an explanation for the low numbers (Winder et al., 2001; Yoshida et al., 2003).

5.1.3 Predator association with scale infestation
The spider abundance data shows no association between spider numbers and scale infestation levels in plots, therefore, it would appear there is no strong predatory relationship, although they may still feed on the scale insect as part of their diet.

The lacewing data on the eggs and larvae are slightly contradictory. In the lacewing egg data analysis scale infestation was cut from the models fitted whilst lacewing larvae abundance data provides evidence of a strong association between lacewing larvae abundance and increasing scale infestation at a plot level. The difference may be as a result of a limitation of the collection method employed for the lacewing egg data as discussed below.
The increased significant difference resulting from the second ANOVA using Middle Caicos data lacewing larvae data further confirms that a link between abundance of the two is occurring. It is reasonable to hypothesise that this is because of predation of the scale insect by the lacewing larvae, considering its known predatory tendencies elsewhere (Rosenheim et al., 1999; Mochizuki et al., 2006).

5.1.4 Predators as a biocontrol agent
From this investigation it appears that spider augmentation is probably not worth investing in spiders as a biocontrol agent, especially considering the resources needed to further investigate which specific species would provide the role best.

Since there is a relationship between lacewings and scale infestation level, combined with lacewing larvae’s known voracity as predators, including on aphids, a possible future threat (Rosenheim et al., 1999; Mochizuki et al., 2006), and the fact that elsewhere they have proven amenable to mass rearing (New et al., 2006), they are a viable candidate for use as a potential biocontrol agent in future (Trouvé et al., 2002). However on Pine Cay this should only follow increased understanding regarding lower insect populations because released populations appear likely to die out, wasting resources. Further research could prove important, including any affects seen on higher-order predators in the environment, to what extent the different instars predate on scale, if they do, and what causes insect death on Pine Cay (Rosenheim et al., 1999)

5.1.5 A new threat
Aphids were discovered during the investigation on numberous trees throughout. This could represent a future threat to the pine trees and could cause what Simberloff & Von Holle (1999) dubbed an “invasional meltdown” (Simberloff, 2006). Investigation into the feeding habits of the ladybird Cycloneda sanguinea L. (see appendix 7.5) did reveal that this beetle feeds on the new aphid threat. Future management may also require generalist predators to control them (Snyder & Ives, 2003; Murdoch et al., 2006)

5.1.6 Experimental limitations and improvements
A lack of plots with trees in provides the first drawback of the investigation, particularly in relation to North Caicos, where the final plot number investigated makes any analysis of the island alone unfeasible. More stratified sampling could help to alleviate this, or alteration to investigating just one tree, the nearest at each transect point, provided it has not already been investigated. This would have led to 60 trees being investigated on all
islands. A secondary positive effect of this would be reducing pseudoreplication and the need to average insect numbers at each plot. It would also provide a more reliable association between scale insect and predator abundance because the scale infestation level and insect numbers would be recorded on a tree level, instead of using plot infestation level. To analyse the effects of density such an experiment would need alteration, instead, the number of trees within a 10m radius around the investigated pine could be used. This would make for more spatially relevant data than the method employed in this report.

One limitation noted with the lacewing egg presence investigation can be seen from the association shown between height of canopy and lack of lacewing egg presence. This could be because eggs are found less on larger trees, however, as the canopy tree canopy height will have often represented the height of pine trees investigated so an alternative hypothesis may also be true. Full size trees were harder to investigate for lacewing eggs and the whole trees could not be checked completely, therefore, it is more likely to report a false negative on adult pine trees which could be what is shown in the relationship between canopy height and lack of lacewing egg presence.

One further limitation has come from the distribution of the number of trees with different scale infestation levels with a decrease for values of 0 and 1 (four and five recordings respectively) and to a lesser degree levels of 2 and 5 (seven and eight respectively). Therefore the power and precision for explanation of these means is less than that for scale infestation levels of 3 and 4.

**5.1.7 Confirming lacewing as a useful biocontrol agent**

Further investigation would now surround confirming the feeding habits of lacewings on scale insect. Lab experiments with various life stages of the lacewing kept with various life stages and sexes of the scale insect would provide evidence of predation evidence of which stages of development would be the most voracious predator and so best biocontrol agent (E.g. Kontodimas et al., 2004; Kaur & Virk, 2012).

Considering lacewing larvae’s propensity to canabilise when food is lacking (Duelli, 1981; Mochizuki et al., 2006; Rojht et al., 2009) it may also be necessary to monitor released populations to discover the optimum release numbers and conditions considering pine size, scale infestation level and time of year (see Daane & Yokota, 1997 for similar). Field experiments could be set up surrounding similarly infested trees with cages to stop insect movement, adding different densities of the predators at different times of year to
monitor any differences. Further control cages would be needed without predator augmentation for comparison as in Murdoch et al. (2006). Monitoring of the affects of other insect species will also be important as part of this process because intraguild relationships have been noted elsewhere which could lead to booms in other populations (Phoofolo & Obrycki, 1998; Resenheim et al., 1999)

5.2 The effect of fire on scale infestation
Fire obviously has an effect on scale insect survival based on the amount of scorched needles seen after a burn. This shows that it could be important for both restorations as a management tool but also in combating the scale insect. It is important to note that increased scorching is also associated with the death of pines and so, how pine and scale insect survival interact will help decide how positive the overall effect of fire really is.

Other important factors to monitor in future are: time taken for levels of scale infestation to return to what they were pre fire and are in the surrounding environment, the growth and extra health seen as a result of the reduced levels of pest, and any other consequences such as possible increased fecundity in adult pines in the intermediate period. Continued monitoring of the pines investigated over the next couple of years will help to define this more clearly.

5.2.1 Experimental limitations and improvements
One limitation with the experiment has come from the lack of a control area outside of the fire zone using the same time interval investigations. This would have made the effects of fire more obvious and helped to neutralise any uncertainty in knowing that temporal changes could have been because of other factors causing a general scale reduction in the ecosystem. This was to some extent dealt with in the analysis by separating the pine trees into two populations of the most and least burnt trees which makes the evidence provided acceptable.

A second improvement to the experiment would have been to investigate more trees before the fire so as to get a fuller picture of the change of all trees investigated from before to after the fire. However time constraints due to possibly changing environmental conditions and so the need to have the fire on a set day made this impossible.

5.3 Restoring the Caicos Pine
The restoration project has been set up as a test plot, with the data collected for this thesis as the baseline for the morphological and infestation characteristics of the planted and wild
pines found within the plots. This included tagging and mapping of all pines so as to make future reassessment easier, including the identification of any new seedlings to appear in the population (likely considering the reproductive status of two mature trees within the plots). Staff at the CPRP will be able to use this baseline data with future monitoring. Of importance will be any characteristics which can be associated with survival or death, such as root collar diameter or planting as a sapling or seedling. In future this data will help develop further planting strategies on the other islands. It may also help set conditional goals for staff to get nursery plant to before planting out.

The planted pine trees all come from a situation of top quality care in the nursery where they are healthy and completely scale insect free. This has provided an opportunity, as part of the baseline data collection, to investigate the scale colonisation dynamics including transport vectors. Of importance will be spatial characteristics of plants which become infected, taking into accounts factors such as, distance to the edge of the plots and proximity to other trees, including, infected wild trees.

Vectors of spread may be monitored through monitoring differences in these spatial characteristics in conjunction with whether plants have certain cage protection or not. If scale insect spread is persistent in all non caged plants and not within caged trees then this provides evidence of which of the possible vectors is important for scale spread (wind or birds and mammals). If there is no difference then this will suggest an alternate vector is important for scale spread, of which small land animals like lizards could be an option.

The proven success or failure of cages to stop scale spread in relation to non-caged plants may be fed directly into management decisions in future on how to protect planted wild trees void of scale insects from getting infected, and could also provide management options for controlling spread from heavily infected trees.

5.3.1 Experimental limitations and improvements

Some differences across the three islands of insect abundances, particularly on Pine Cay have been shown in this project. It is therefore possible that optimum planting strategies for planting of Caicos Pine trees could be different between islands. Restoration plots on Middle Caicos and North Caicos would have provided a good comparison for this being the case.
5.4 Combining fire and biological control to improve restoration

Caicos Pine survival is and should be one of the explicitly stated objectives of the CPRP project, although success should be measured by broader factors than solely its survival (Lindenmayer et al., 2002). For success an integrated management strategy which supplements the wild populations whilst establishing new populations, using assisted migration should be employed (Oldfield, 2009; Vitt et al. 2010). This should include a combination of the management techniques discussed in this paper, including ongoing monitoring with control comparisons. Restoration sites could be burnt providing the multiple objectives of clearing vegetation to reduce pine competition, provide new planting sites, and reducing scale infestation. This could be followed by planting to bolster the populations and aid the spread of the pine. Finally the natural population of predators such as lacewings could be bolstered with releases.

Any biocontrol breeding programme would need to avoid inbreeding and disadvantageous characteristics entering the population which reduce survivability when reintroduced back into the wild, such as loss in predator evasion adaptations and reduced fecundity (see Reisenbichler & Rubin, 1999; Heath et al. 2003; Kraaijeveld-Smit et al. 2006; Tayeh et al. 2012). Starting with a maximal population size and splitting into sub populations, with crossings between these after signs of inbreeding, combined with regular introduction of wild individuals will help avoid genetic drift affects, whilst rearing in natural conditions will reduce negative evolutionary traits (Heath et al. 2003; Kraaijeveld-Smit et al. 2006; Williams & Hoffman, 2009; Tayeh et al, 2012).

5.5 Further restoration suggestions

When devising replanting and reforesting three spatial levels should be considered:

1. Where in the landscape to plant trees – taking into account climate change and closeness to mature pines
2. Planting regimes – focussing on what helps planted trees survive and fend off the scale insect
3. Conditions of individual trees – survival of pine trees and protection from scale

When choosing where to place restoration plots habitat suitability mapping considering factors such as protected status, edaphic and hydrological conditions, vegetation type, proximity to human developments, proximity to healthy pines, the likelihood of crown fires and importantly future climate change scenarios is vital in helping to make the correct
management decisions (Allen et al., 2002; Vitt et al., 2010; Harris et al., 2006; Hoegh-Guldberg, 2008; Rossatto et al., 2012). This could include local assisted migration because the normal risk of this technique, species becoming invasive is not a problem (McLachlan, 2007; Ricciardi & Simberloff, 2009; Loss et al., 2010). Landscape heterogeneity and variation in tree densities will provide opportunities for species with different habitat adaptations in the environment to be accommodated (Allen et al., 2002; Ruiz-Jaén & Aide, 2005).

Continued monitoring of effects on the surrounding environment including the ecosystem processes, such as the biogeochemical and nutrient cycles, and the vegetation structure will be important to ensure conservation success, assists with learning and will help improve management decisions in future (Lindemayer et al., 2002; Ruiz-Jaén & Aide, 2005; Eckehard et al., 2008). This includes monitoring pineyards species such as the endemic curly tailed lizard (*Leiocephalus psammodromus*), the Thick-billed Vireo (*Vireo crassirostris*) and *Stenandrrium carolinae* Leonard & Proctor (Allen et al., 2002; Pienkowski, 2005; Malumphy et al. 2012).

When actually planting, local factors and planted tree condition will be important factors to manage. Nursery planting has been proven to improve planted tree condition under summer drought conditions (Gomez-Aparicio et al., 2004) and young pines were noted growing up through *Strumpfia maritime* Jacq. which grows, therefore there may be species to which this applies which could help reduce costs of watering monetarily and in terms of manpower.

Investigation into various watering regimes could also provide valuable insights into the best methods of restoring the pine at minimal cost. It seems obvious that continuous watering will have a positive effect on plant survival over a control (80% mortality vs complete survival with spring and summer watering - de Luis et al., 2011) in an arid climate. However the best watering levels and times of year for watering need to be investigated for maximum survivorship of trees and reduction of scale infestation levels, whilst taking into account interactions with Ectomycorrhizal fungi which could lower water requirements (Garbaye, 2000; Hobbie & Colpaert, 2004; Swaty, 2004; Kazantseva et al., 2009; Rossatto et al., 2012). Experimentation should build in monitoring of site specific conditions like rainfall, temperature and expected evapotranspiration which could be used
to create a model to suggest an adaptive water regime to be set up based on expected water availability conditions at any specific site.

5.6 No more outbreaks
To stop further IS outbreaks in future it is vital to try to change the behaviour of people that bring risk associated products into the country without appropriate caution. This would require identifying the main reasons behind dangerous behaviours and to work out the likelihood of changing them through discovering out how much plasticity there is in people’s choices (Schultz, 2011). By increasing awareness of the role of trade with invasive species and of the ecological and economic implications of allowing their establishment ($120 billion annually in the US alone – Pimentel et al., 2005) could help change individuals opinions and behaviours towards biosecurity and help the TCI government set up and implement better risk assessment leading to stronger legislation surrounding importation and quarantine (Lodge et al., 2009)
6. Bibliography


Recovery of the endemic Caicos Pine: Invasive pest management and restoration


Alex Hudson
Recovery of the endemic Caicos Pine: Invasive pest management and restoration


Recovery of the endemic Caicos Pine: Invasive pest management and restoration


Recovery of the endemic Caicos Pine: Invasive pest management and restoration


Alex Hudson


Recovery of the endemic Caicos Pine: Invasive pest management and restoration

Trimble (2012) [Online]


7. Appendix

7.1 Using a watch to randomise
The milliseconds on a watch were used for randomisation. Number ranges were assigned to bearings to be taken and quadrats to be selected in a grid system. For directions 20 degree intervals were chosen across a range from 80 to 260 degrees with 10 millisecond intervals assigned to each as in Table 7.1.

Table 7.1: Possible options for random selection of transect direction

<table>
<thead>
<tr>
<th>Direction</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>140</th>
<th>160</th>
<th>180</th>
<th>200</th>
<th>220</th>
<th>240</th>
<th>260</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milliseconds</td>
<td>0-9</td>
<td>10-19</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
<td>90-99</td>
</tr>
</tbody>
</table>

In the restoration plot set up North to East quadrant being assigned to 1-24 milliseconds, the East to South quadrant was assigned 25-49 milliseconds, the South to West quadrant to 50-74 milliseconds, and the West to North quadrant assigned to 75-99 milliseconds.

7.2 Pine transport and planting methods
The planted trees were brought over to pine cay by boat and so, although covered for the journey may have experienced salt spray. They were therefore watered and their needles mist sprayed on arrival to the island to replace lost water through evapotranspiration and minimising plant stress. Further to this they were left in shade to recover for 1 hour at least before planting. In each plot four larger saplings were planted and 21 smaller saplings and seedlings.

When planting the surface detritus and soil was first cleaned away from the ground surface of the planting spot to avoid contamination from possible fungi found there. A hole was dug into the earth to a sufficient depth to accommodate the root ball of the plant, making sure to remove any large and dead roots which again could provide fungal infection to the trees. The soil dug up from the soil was cleaned of root and large stones to remove any possible root infection mediums and to lessen the chance of air pockets in the soil, which cause root moisture loss. The further reduce this soil was chopped when still in the soil using a spade head.
The bottom of the hole was made flat to support the trees which were placed to make sure the topsoil of the root ball was level with the surround soil outside of the hole. This helped to stop water runoff from being planted above the surrounding soil line and stopped the base of the trunk from being rotted from planting below the surrounding soil line. The surrounding soil was then used to infill around the tree making sure that the root ball did not break up.

Once secure in the soil a small bank of nearby soil was built around the tree to avoid water runoff when watering. The plant was watered so as to wet the root ball and surrounding soil completely in order to reduce water loss through osmosis to the surrounding area.

7.3 Use of Clinometer
Measure 20m away from the from the tree was measured in the ‘flatest’ direction, then the clinometers was used to get a number by looking back towards the tree and tilting you head back until looking at the apex of the tree. The number was then divided by 100, multiplied by 20 and the height to the person making the recording’s eye added on.

7.4 Cage protection
The enclosures were set up as circular cylinders around the plants using *Casuarina equisteifolia* (an island invasive cedar) stakes to support them. On the larger saplings the diameter was c. 1m and on the smaller ones 50cm. All were made with chicken wire mesh fencing which was 5ft high. On the smaller plants the tops were pinched together and folded over to stop entry from above, for the larger plants a top was made out of extra mesh fence and fly wire and attached.

7.5 Predator experiments

*Parasitic wasps*
Needles were collected from infected pine trees and stored in small plastic tubs (4.5cm tall and diameter 11.5cm), with holes in the lids. These were labelled, stored and monitored for parasitic wasps emergence. Needles were selected with larger adult scale on them without waxy white covering, looking enlarged and brown. These were thought to be characteristics parasitisation after noting similar characteristics on scales in the field with small mining holes, expected to be from wasps (pers. comms Malumphy).

*Lacewing larvae and ladybirds*
Lacewing larvae and ladybirds were collected from the field and put into round plastic food
tubs (4.5cm tall and diameter 11.5cm) with holes in the lids. Needles with scale insect were
added to these and they were monitored for survival. Collection numbers were limited by
the amount found within the field and not wanting to take too large. Some lacewing died in
transit.

Water was placed in plastic bottle to lids with a rock in the middle for insect access. For the
only surviving/unescaped ladybird aphids were also provided when possible.

7.6 Insect transects

7.6.1 Middle Caicos
The first six transects were carried out in the main pineyard near to the Permanent
Monitoring Plots (PMP)(See Earle-Mundin, 2010). The first was carried out using the edge
selection method from the PMPs. The next four were carried out using parallel method.
The sixth eighth and tenth to twelfth transects were chosen using the random map point
method. Transects seven to nine were investigated in a pineyard to the West. Transect eight
and nine were selected to the South of the previously investigated transects (Green, 2011).
Transect nine was started by heading due South from the end of transect eight 200m.

7.6.2 North Caicos
The first two transects were carried out in the area of pine surrounding the permanent plots.
The starting points of each were decided using the edge selection method. Transects three
to seven were carried out in the larger pineyard area to the West of the permanent plots.

The third transect was carried out in a smaller open area to the West of the permanent plot
pineyard after travelling through an area of thick vegetation. On first entering the palm
dominated the edge selection method was used to select the first point. The transect was
continued in the direction decided with points at 50m intervals until five had been done.

Further South in a second palm dominated area transects four to seven were carried out, the
starting point for four being chosen using the edge selection method and the rest using the
parallel method. Transects eleven and twelve had starting points chosen further South than
these using the random map point method.

The final area investigated was on the South of the island in the ready money pineyard off
of the road near Ready Money Gardens. Transect eight was using the edge selection

Alex Hudson
method from the edge of the road. Transect nine was started 200m in the North direction from the last point of the eighth transect. The tenth transect was started 200m West of the final point in the ninth transect. 280 degrees was used for these three transect directions being 180 degrees in the opposite direction of the usual 100 degrees so that they ended being in the same direction.

7.6.3 Pine Cay
The first and third starting points were selected using the random map point method within areas previously not investigated for pine density so as to cover more area for the partner project (See Mark, 2012). These were found in the south of the main pineyard on the island. The second and fourth transects were started by travelling North from the final point of the previous transects. Two then headed on the 100 bearing again, therefore heading further East. Transect four was initially going to return on a bearing 280, making it parallel with three, however this led the second point to be within a lake area not possible to investigate and therefore it heading on a bearing of 100 from the starting point instead. Transect two was 100m away from one, unlike other transects (usually 200m) because it would run into one of the previous year transects if located at 200m. The remaining transects were started using the random map point method.

7.7 Cleared vs Uncleared area investigation
In November 2011 a small area with thriving pine trees was cleared of other vegetation around the trees next to one of the Pine Cay sand buggy roads. The area was circa 20m x 30m. Within this area a 10m x 10m plot was set up to investigate the pine community and vegetation community on 20th June 2012.

Opposite the road was another area similar in appearance to the cleared area, i.e with healthy mature pines, but without other vegetation clearance around the trees. The dominant understory vegetation here was tall Cladium mariscus, Strumpfia maritima, Moseira longipes with some Stenostonum myrtifolium. It was also noted that the ground cover included thicker and greater amounts of fallen pine needles. A second plot of 10m x 10m was set up in this area on 28th June 2012 to compare against the cleared area plot.

The two plots were investigated on the 27th and 28th June 2012. Plots were set up using one side of the road as one side of the plot, measuring 10m. A compass was then used to visualise 90 degrees from the two corners and 10m measured away from the base side. At each corner marker stones were used with/or steaks with blue flagging tape tied to the tips.

Alex Hudson
Correct size was tested by measuring from one corner to the opposite corner making sure it is as close to 14.1421 (from Pythagoras theorem).

Within each plot the tallest vegetation height was recorded and the % canopy cover this extended over. A species list was created of all vegetation within the plots. An estimate for mould, scale and canopy loss and percentage of ground covered by vegetation. A recording of disturbance type. Whether pine trees had cones and of what type: 1st year, 2nd year or 3rd year. The numbers of pine trees were also recorded splitting them into six categories: New seedlings (being <5cm tall); Seedlings (as standard); Saplings (as standard); Saplings with cones; Mature trees (trees as standard size but with cones) – including a recording of those with green unopened cones (in brackets); mature trees (trees as standard but with no cones). Binoculars were used to confirm cone types and to check trees for scale and mould, otherwise not visible from the ground.

For each class trees were counted by walking around the plot to find the trees and tying flagging tape to them, or next to them whilst counting to ensure none were counted twice. On removing the tape the count was made again to confirm the number. One final confirmation was made by counting the numbers of flagging tape collected too.

The task was harder in the uncleared plot because of thicker vegetation and ground needles therefore it is more likely some smaller seedlings and saplings may have been missed from the counts.

<table>
<thead>
<tr>
<th>Plot type</th>
<th>Canopy height (m)</th>
<th>Canopy cover (%)</th>
<th>Ground cover (%)</th>
<th>Infest</th>
<th>Cones</th>
<th>Mature (with second year cones)</th>
<th>Immature</th>
<th>Saplings (with cones)</th>
<th>Seedlings (New – below 5cm tall)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleared</td>
<td>7</td>
<td>5</td>
<td>30</td>
<td>12</td>
<td>(9)</td>
<td>1</td>
<td>40 (2)</td>
<td>88 (5)</td>
<td>46 (24)</td>
</tr>
<tr>
<td>Not cleared</td>
<td>8</td>
<td>5</td>
<td>85</td>
<td>13</td>
<td>(11)</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Class size of below 5cm for new seedlings may have proved a bad choice because seedlings in the non-cleared plot were all large, possibly due to extra leaf litter accumulation forcing more growth for new seedlings or stopping the ability to see them.

Alex Hudson