Invasive plants in the Turks and Caicos Islands

By Chloe Hardman

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List of acronyms and abbreviations

AUC: Area Under Receiver Operating Curve
CBD: Convention on Biological Diversity
DECR: Department for Environment and Coastal Resources
DEFRA: Department for the Environment, Food and Rural Affairs
GISD: Global Invasive Species Database
GISP: Global Invasive Species Programme
GLM: General Linear Model
GPS: Global Positioning System
GSPC: Global Strategy for Plant Conservation
ISSG: Invasive Species Specialist Group
IUCN: International Union for Conservation of Nature
MaxEnt: Maximum Entropy Modelling
NDVI: Normalised Difference Vegetation Index
RAMSAR site: Wetland of international importance under the Ramsar Convention.
TCI: The Turks and Caicos Islands
TCNT: Turks and Caicos National Trust
UKOT: United Kingdom Overseas Territory
UTM: Universal Transverse Mercator
Abstract

Invasive plants present a significant and growing threat to biodiversity worldwide. In order to mitigate this threat, baseline information on the status and distribution of invasive plants is needed. This project aimed to predict suitable habitat for invasive plants in the Turks and Caicos Islands, quantify their impact on native flora and survey awareness of these threats. Five focal species were investigated: two trees *Casuarina equisetifolia* and *Leucaena leucocephala*, two shrubs *Scaevola taccada* and *Ricinus communis* and a climber *Jasminum fluminense*.

Field surveys revealed the habitat preferences of the invasive plants, by using presence points to predict suitable habitat with MaxEnt software. Disturbance, particularly near roads was found to be a key factor related to the presence of invasive species. Native species richness in areas invaded by *C. equisetifolia* was lower than paired uninvaded areas. Predicted suitable habitat for the focal invasive plants overlapped with that of three endemic plants, based on MaxEnt models. This body of evidence is the first scientific study to show that invasive plants are a threat to biodiversity in TCI and the maps produced highlight areas of highest concern to help prioritise conservation.

Social surveys showed the majority of TCI residents recognised *C. equisetifolia* and *L. leucocephala* and had noticed an increase in their number. However, most respondents were unaware that the plants did not belong in TCI. Increasing awareness of invasive plants is a key conservation recommendation and this was initiated through the production of educational posters for the Turks and Caicos National Trust. Improving biosecurity checks and banning import of known invasives would be beneficial, particularly in areas highlighted as at risk of invasion. There is much potential to reduce future introductions and impacts of invasive plants in the Turks and Caicos Islands in order to conserve the islands unique biota and identity.

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INTRODUCTION

1.1 Invasive species: a threat to biodiversity

1.1.1 Biotic homogenisation

Invasive species are a major driver of global environmental change (Vitousek et al 1997). We are at risk of entering a new geological era, the homogeneic, where a few prolific species dominate many habitats (Olden et al 2005, Lockwood and McKinney 2001). Preserving integrity of place in the face of rapid globalisation is a major challenge for the next century.

Not all introductions of non-native species are harmful, in fact 80-90 % of established non-native species have minimal detectable effects (Byers et al 2002). Yet many species create problems when they spread in areas outside their native range and these are termed invasive species. Their effects include altering the structure and function of an ecosystem, reducing the diversity within an ecosystem or degrading human health or wealth. The impact of invasive species may be currently underestimated due to lag-times between invasion and effect (Simberloff 2009).

1.1.2 Extinctions

The role of invasive species in causing extinctions is debated. Gurevitch and Padilla (2004) calculated only 6% of all species on the IUCN Red List to be directly affected by alien species. When Clavero and Garcia-Berthou (2005) performed a similar analysis that included extinct species in the IUCN database, they found causes for 25% of the 680 extinctions, 54% of which involved invasive species. Invasive species are often part of multiple synergistic threats leading to native species decline (Didham et al 2005). There is concern that threats such as habitat degradation and climate change are likely to facilitate invasions in future (Dukes and Mooney 1999).

1.2 Why are invasive species interesting to science?

Invasions present good experimental systems for testing concepts in ecology, such as understanding basic processes in population biology (Sakai 2001), ecosystem function and species evolution (Pysek and Hulme 2009). The evolutionary impact of invasive species on ecosystems is poorly understood. By removing the geographical barriers needed for allopatric speciation, human transport of populations could reduce rates of speciation in future. Biotic homogenisation and the simplification of biotic
interactions may reduce selection pressures and slow rates of evolution (Olden et al 2005). In addition, invasive species can influence the evolutionary path of native species through competition, niche displacement, predation, hybridisation and introgression (Mooney and Cleland 2001).

Understanding the invasion process requires insight into both the species and environment it is invading. Invasions are highly context specific and a species must overcome environmental barriers to become invasive (Richardson and Pysek 2006). The three main stages in the invasion process are escaping, establishing and becoming a pest by having an impact over an expansive range (Williamson and Fitter 1996). Each of these stages may fail hence why only a subset of native plants becomes invasive (Figure 1).

**Figure 1: The invasion process and management strategies possible at each stage (modified from Lockwood et al 2006 and Williamson and Fitter 1996)**

1.3 How can invasion science inform conservation?
A key challenge in invasion biology is to predict which species are likely to cause damage in which areas and prioritise conservation efforts accordingly. The long
The niche of an organism describes its ecological role and the ranges of conditions and resource qualities in which it can exist (Ricklefs and Miller 2000). Lower diversity and empty niches on islands may make them intrinsically more susceptible to invasion. However, evidence for invaders filling empty niches is lacking for terrestrial plants (Noble 1989). The relationship between species diversity of a community and the resistance of the community to invasive species is also more complex than first appears. Diversity was found to correlate positively with invasions on a large scale (Levine 2000) but negatively in smaller scale grassland experimental plots (Tilman 1997).

Other factors that affect the invasibility of a community are disturbance, resource availability, propagule pressure, climate, competitors, and predators (Byers and Noonburg 2003). Propagule pressure is a key factor in determining the likelihood of success of an invasion (Von Holle and Simberloff 2005). By producing many propagules, plants can survive in a number of locations and overcome effects of herbivory and competition. Invasive species that are less genetically similar to native biota tend to be more successful in invasive grasses in California (Strauss et al 2006). Species which are commensal with humans make up a large proportion of invaders (Noble 1989). However, making generalisations about characteristics of successful invaders is difficult because there are always exceptions. Perhaps the best principle is that species invasive in one area are likely to be in another (Baskin 2002).

Invasive species management can focus on each of the four main stages in Figure 1, prevention, early detection, eradication and control (Wittenberg and Cock 2001). Scientists can inform and help prioritise policy and management at each of these stages. Prevention and early detection are the most effective and cost-efficient options and scientists can help identify species, areas and transportation vectors that pose high risks. When an invasive has been present for many years, control may be the only feasible option. Complete eradication is more resource-demanding, although
has been possible in a few cases such as elimination of sandbur (*Cenchrus echinatus*) from Laysan, a 4.1 km$^2$ Hawaiian island (Simberloff 2009). Scientists can help find the most effective management solutions through predictive modeling and controlled experiments.

1.4 Policy responses

1.4.1 International

International efforts to coordinate a global strategy on invasive species include the Global Invasive Species Program (GISP) and the IUCN Invasive Species Specialist Group (ISSG). The ISSG, founded in 1994, has over 170 voluntary members from more than 40 countries. It aims to help build capacity, provide advice and facilitate exchange of information for managing invasive species. In 1996, the first UN international meeting on invasive species was held in Norway. The following year, GISP was established. This multi-disciplinary group includes scientists, environmentalists, lawyers, natural resource managers and policy makers. One of their key outputs has been a Global Strategy on Invasive Alien Species and Invasive Alien Species: A Toolkit of Best Prevention and Management Practices (Wittenberg and Cock 2001). The Global Invasive Species Database (GISD 2009) was also developed by GISP and is managed by ISSG. This is a searchable online database summarising information on ecology, distribution, impacts and management.

The Convention on Biological Diversity (CBD 2009) calls for action to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species" (Article 8h). Two of the CBD’s cross cutting initiatives “Invasive Alien Species” and “The Global Strategy for Plant Conservation (GSPC)” include guidance on implementing article 8h. The Invasive Alien Species initiative provides guidance on implementing international and regional agreements on managing invasive species. The GSPC is an initiative to set quantitative targets for plant conservation. There are 16 outcome-orientated targets including Target 10, to put “management plans in place of at least 100 major alien species that threaten plants, plant communities and associated habitats and ecosystems.” This target has been reached, but there is now a need to adapt the management plans for local use and ensure the plans meet a consistent standard (GSPC Review 2009).
1.4.2 National
Developing a management plan for an invasive species involves setting clear aims and objectives which fit into existing legislation to help achieve the ultimate goal of restoring a healthy ecosystem. To be successful, the programme should involve stakeholders from the outset. For example, horticulturalists, tourism and trade businesses, the government department for the environment, community residents and department of health biosanitary inspectors should all be involved in managing invasive plants. Making a code of practice widely available is a good start, as exemplified by South Georgia’s biosecurity policy (South Georgia Biosecurity 2009). Before starting their journey to South Georgia, visitors must carry out bootwashing and checks of clothing and luggage. On arrival visitors must undertake a self audit to check for soil and organic material and sign to declare they have done so.

In TCI, biosecurity legislation stems from the plant protection ordinance (1921). Its purpose is to regulate invasive plant species or imported plants that may spread disease to native plants. The Governor can prohibit the importation of certain plants and the list of banned plants is under review (DECR 2009). Imported plant products are required to have a phytosanitary certificate under this ordinance. As part of the UKOTs Environmental Charter signed in 2001, the plant protection ordinance was updated to “attempt the control and eradication of invasive species”. In implementing this charter it is important that one government department has lead responsibility (UKOTCF 2009). A new Wildlife Protection Act is being developed to help TCI ratify international agreements such as the CBD (Manco, B. N. pers comm.).

1.5 Why is research needed in TCI? 
The Caribbean is a priority region for conservation under many prioritisation schemes, such as hotspots (Myers et al 2000) and TopSpots (Fa and Funk 2007). This project will focus on the Turks and Caicos Islands, which have over 550 plant species, nine of which are endemic (Oldfield et al 1999, Kew 2009). The area is a regional priority for the conservation of cacti and succulents. Other notable wildlife includes the endemic rock iguana (Cyclura carinata), which has been the subject of recent conservation work involving the removal of feral cats from certain islands (Mitchell et al 2002).
Small island developing states are particularly at risk from invasive species because trade, tourism and transportation are high, increasing the risk of introductions via ships and imported goods. Throughout history, humans have introduced many plants to small islands because they viewed the native flora as impoverished. Food, fuel, medicines and animal fodder crops in particular were transported across oceans to give new immigrants a sense of security (McNeeley 2001). There is evidence to suggest that invasive species can facilitate further invasions through a process of invasional meltdown (Simberloff and Von Holle 1999). Prevention measures and early detection systems are now needed more than ever.

The baseline data needed to develop an invasive plant management plan was lacking from the Turks and Caicos Islands. Plant species lists had been compiled but data on invasive plants was limited to a small number of point observations (Hamilton, M.A., pers. comm, 2009). This reflects a wider problem within the UK overseas territories of a lack of species inventory data limiting conservation strategy development (Oldfield and Sheppard 1997). This project aims to meet this data need and assess resident awareness to ensure scientific communication to the public is pitched at an appropriate level. This will assist Turks and Caicos National Trust (TCNT) and Department for Environment and Coastal Resources (DECR) in developing invasive species management strategies.

1.6 Aims and objectives
Aim: To predict areas of suitable habitat for invasive plants in TCI, quantify invasive impact on native flora and survey awareness of these threats.

Objectives
1. To survey distribution of five non-native plants (Casuarina equisetifolia, Jasminum fluminense, Leucaena leucocephala, Ricinus communis, Scaevola taccada) and use this data to predict areas of suitable habitat for invasive plants across TCI
2. To quantify the impact of Casuarina equisetifolia on native plant species richness
3. To use social surveys to reveal how far locals can distinguish between native and invasive plants and assess awareness of the invasive plant problem in TCI
1.7 Terminology
To ensure consistency of meaning, the following IUCN definitions are used in this study.

“Invasive species (or invasive alien species) means an alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity.”

“Alien species (non-native, non-indigenous, foreign, exotic) means a species, subspecies, or lower taxon occurring outside of its natural range (past or present) and dispersal potential and includes any part, gametes or propagule of such species that might survive and subsequently reproduce.”(IUCN 2000).

1.8 Scope of the study
Chapter 2 places this study in the context of the scientific literature on the impacts of invasive species, methods of quantifying impact and predicting suitable habitat. Previous assessments of awareness of invasive plants are reviewed. The study area and focal plants are introduced, along with the history, politics and current conservation work in TCI.

Chapter 3 outlines the methods used for the three objectives, including field survey techniques and data analysis. GIS, MaxEnt and statistical analyses in R are described.

Chapter 4 describes the results obtained. The influence of disturbance is investigated and the outputs of MaxEnt models are shown including maps of predicted suitable habitats. The impact of C. equisetifolia on native species richness is examined and responses of the public awareness survey are summarised.

Chapter 5 discusses how these results fit into the broader picture and what the implications for conservation will be. It also critically reviews the strengths and weaknesses of the project and makes suggestions for further work.
2. BACKGROUND INFORMATION

2.1 Impacts of invasive species

The impacts of invasive species are wide ranging and can be broadly classified into ecological, economic and environmental. Economic impacts of invasive species have been estimated based on control cost and damage costs. For example, the aquatic plant *Hydrilla verticillata* costs Florida about $14.5 million in control and still prevents the use of two recreational lakes, costing an extra $10 million annually (Pimentel *et al* 2005). If the associated loss to biodiversity, ecosystem services and aesthetics was included, costs would be much greater. These nonmarket values can be estimated using techniques such as willing-to-pay surveys (McIntosh *et al* 2009).

Environmental impacts of invasive plants can include changes to soil chemistry (Ehrenfeld and Scott 2001), geomorphology and hydrology (Gordon 1998). For example, *Tamarix* spp. can have impacts on nutrient cycling, fluvial geomorphology, fire regimes and native species regeneration rates (D’Antonio and Vitousek 1992).

Ecological impacts can be subdivided according to scale. Invasive species may affect individual native species through direct competition for nutrients or light, or through indirect paths. Invasive garlic mustard (*Alliaria petiolata*) was found to impede formation of mycorrhizae on which native plants depend (Roberts and Anderson 2001). Population growth rates, community diversity, or ecosystem cycles may all be affected by invasions (Parker *et al* 1999). Invasive plants can alter the genetic structure of a community, especially through hybridisation with natives (Daehler and Carino 2001).

2.1.1 The focal species and their impacts

The five focal species (Photos 1-5) are described in detail in Appendix 1: Table 1. All appear to have been deliberately introduced outside their native range, whether for ornamental purposes (*J. fluminense, R. communis, S. taccada, C. esquisetifolia*), as a beach stabiliser (*S. taccada*), windbreak (*C. esquisetifolia*), fodder crop (*L. leucocephala*) or for oil (*R. communis*). Three have native ranges in Africa (*J. fluminense, R. communis, S. taccada*), one in Mexico (*L. leucocephala*) and two in Australia and SE Asia (*C. esquisetifolia, S. taccada*).
Both *L. leucocephala* and *C. equisetifolia* are listed amongst the 100 worst invaders in the world (GISD 2009). There is evidence that both these trees change the nutrient cycling of the ecosystems they invade (Parrotta 1999).

Photos 1-5: The five focal species © Chloe Hardman

*C. equisetifolia*
Comparative studies of forests with and without *L. leucocephala* invasion showed species richness of native plants was lower in invaded habitat. Once *L. leucocephala* had established, native Hawaiian vegetation could not replace it, but aggressive non-native plants could (Yoshida and Oka 2004). Experimental plots showed seedling germination was impaired under *L. leucocephala* (Jurado *et al* 1998). This may be because of accelerated soil acidification rates (Walton 2003).

Scientific evidence for the impact of *C. equisetifolia* on native vegetation is lacking. There is anecdotal evidence for a change from dune plant communities into closed-canopy forest following invasion by *C. equisetifolia* (Gordon 1998). Concern over the impact on nesting of loggerhead turtles in Florida prompted a study in which *C. equisetifolia* was removed from areas of beach to investigate its impact on incubation temperatures (Schmid *et al* 2008). *C. equisetifolia* was not found to affect incubation temperatures differently from native vegetation, but observations suggest the shallow roots and tendency to fall over in strong winds can inhibit sea turtle nesting.

2.2 Quantifying the impact of invasive species

There are a range of equations to calculate invasive impact for a species (Lockwood *et al* 2006). However it should be recognised that impacts are complex and single linear relationships are an oversimplification. These calculations do, however, provide a way to model impact under different scenarios, for example the Parker formula shown below:

Equation 1:  \[ I = R \times A \times E \]

Equation 1: Impact of an invasive species where \( I \) = impact, \( R \) = range size of invasive populations, \( A \) = abundance or biomass per unit area, and \( E \) = effect per capita or per unit biomass on native species, which may vary between habitats (Parker *et al* 1999).

All these parameters are challenging to estimate in the field (Lockwood *et al* 2006), particularly effect on native species (E). Coupling cause and effect in ecology requires carefully designed observations or better still a controlled, replicated, randomised experiment. To attribute an impact to invasive plants, we need to be confident that the impact is not due to other factors, such as habitat modification.
Habitat modification and invasion are often linked. For example, many invasive plants colonise disturbed areas faster than intact habitats (Meyerson and Mooney 2007). This leads to a debate over whether it is the habitat change, or the invasive species driving the impact on native species. MacDougall and Turkington (2005) articulate this debate in terms of the driver and passenger models.

In the driver model, exotic species outcompete native species through a direct interaction. In the passenger model, non-interactive factors favour dominants, such as habitat disturbance. MacDougall and Turkington (2005) found evidence for the passenger model, based on exotic grasses in an oak savannah. However, driver and passenger models are extremes of a continuum and an ecosystem is likely to lie between the two (Didham et al. 2005).

Understanding the multiple drivers of species loss and how they interact is crucial in conservation. If an ecosystem is tending towards the passenger model, invasive management could focus more on habitat manipulation than invasive removal. For example, changing soil nutrient levels or minimising disturbance could help reduce the spread of invasives (Daehler 2003).

Decisions on invasive plant management need to be based on sound scientific evidence that the non-native plant is actually having a negative effect. Too often, a xenophobic attitude towards non-native plants replaces science as a basis for decision-making (Brown and Sax 2004). The impact of an invasive plant could be quantified by comparing native plant communities before and after invasives are removed, and comparing the removal area with an area where invasives remain. This would also provide an interesting study of how long it takes for native plants to recolonise. For example, removing invasive grasses resulted in increased soil nitrogen and native shrubs density (D’Antonio et al. 1998). A removal experiment would be an interesting trial for potential control strategies, which can have unexpected consequences (Zavaleta et al. 2001). However, this was not feasible in the timeframe of the project so areas with and without invasives were compared.

Similar comparisons were made to study the impact of *Acacia longifolia* on dune plant communities in Portugal (Marchante et al. 2003). Twelve permanent plots were
established, six with and six without *A. longifolia*. Species richness and evenness was lower in invaded plots. This experiment clearly showed that *A. longifolia* was changing the community composition towards monospecific stands. Obtaining estimates of the effects of invasive plants is possible, so now range size must be estimated.

2.3 Predicting suitable habitat for invasive species using MaxEnt

Predicting ecological niches and distributions by relating species presence points to environmental variables is a rapidly developing field. A number of modelling methods exist including GARP, BIOCLIM and MaxEnt. For this study MaxEnt was chosen because it can cope with a large number of features (resulting from our fine spatial scale grids) and relatively few sample points (Pearson *et al.*, 2007). In comparisons to other methods, MaxEnt has performed well (Elith *et al* 2006, Peterson *et al* 2007, Phillips *et al* 2006, Roura-Pascual *et al* 2009).

The applications of MaxEnt can be broadly classified into ecological niche modeling and distributional modeling (Peterson 2006). The realised distribution is affected by dispersal ability, evolutionary history, stochasticity and biotic interactions (Phillips 2008). Insufficient data for these factors were available so ecological niches were modeled rather than distributions. The niches predicted by the models may not be the fundamental niche because observed points may not have been at the extremes of the species’ tolerance. However the models are still considered useful because they provide an indication of potential suitable habitat, showing where a plant is most likely to spread if propagules reached that area.

Environmental variables are entered into MaxEnt as grids with a value in each cell. MaxEnt assigns a probability of species presence to each grid cell across a map of the study area, based on environmental suitability (Phillips 2004) and presence data. The environmental predictors constrain the model, according to our limited information on species distribution. The model of maximum entropy produced is the most unconstrained model, given the environmental predictors.

MaxEnt produces a map output in which each grid cell is assigned a cumulative logarithmic probability between 0 and 1. The output accuracy is tested by dividing
the data into training data (used to build the model) and test data (used to test but not build the model). The range area that did not contain a test presence point is calculated, termed the omission error. By taking a different random subset for use as test data, the consistency of the models accuracy can be tested (cross-validation). The contribution of each environmental variable to the model is calculated by MaxEnt using three types of Jackknife tests. Each environmental predictor is taken out in turn and the regularized training gain, test gain and AUC value that each predictor contributes is calculated (Phillips *et al* 2006).

Different models can be compared using the area under the receiver operating curve (AUC). It is calculated using pseudo-absences generated by randomly sampling the background grids rather than using true absence points. AUC represents the chance that a randomly chosen presence point ranks as more suitable habitat than a random background point. A value of 0.75 or above is considered the threshold for a useful model (Elith 2002). Models with the highest AUC values were chosen since this is less subjective than choosing a model visually based on prior expectations and is generally accepted as the best measure for evaluating model performance (Elith *et al* 2006).

Cumulative maps can be converted to binary maps by setting a threshold. For example setting the minimum training presence threshold produces a map showing the smallest range of suitable habitat that includes all the training data points. This should not be interpreted as a definitive map because the boundaries will have wide error margins, but it gives a general indication of areas most at threat from invasion.

### 2.4 Surveying resident awareness of invasive plants

Many invasive plant problems result from deliberate introductions and lack of public awareness about the threat posed by invasive plants is a common problem. In San Lorenzo, Argentina, lack of community understanding of the threat is one of the main causes of the invasive plant problem (Speroni *et al* 2003). In California, biological invasion and the ecological or economic impacts of weeds were unfamiliar to most survey respondents (Colton and Alpert 1998). The low awareness of invasive plants found in Giant City State Park, Illinois, USA was used to inform interpretation boards and control strategies (Baker *et al* 2005). Most social studies on awareness of
invasive plants have been done in the USA, so an awareness survey in TCI was considered important because this data has never been collected before.

Awareness in the horticulture industry was high in St Louis, USA (Burt et al 2007) and targeting horticulturalists can be a good way to encourage use of native rather than non-native landscaping plants. The DEFRA horticultural code of practice to prevent the spread of invasive species provides good advice here (DEFRA 2005). These guidelines for using, controlling and disposing of invasive plants include tips on avoiding importing pests in soil, the importance of identifying plants properly and how to comply with legislation.

2.5 Study Area

2.5.1 Overview

Turks and Caicos Islands (Figures 2, 3) are a cluster of islands of total area 430 km² in the northern Caribbean region (21° 45’ N, 71° 35’ W). Biogeographically they are contiguous with the Bahama Archipelago and sit in the Atlantic Ocean. Nine of the 40 or more islands are inhabited permanently (Providenciales, Pine Cay, Parrot Cay, North Caicos, Middle Caicos, South Caicos, Big Ambergris Cay, Grand Turk, and Salt Cay), with two more being developed to have permanent settlements soon (West Caicos and Dellis Cay) (Manco, B. N. pers.comm. 2009).
The islands are mostly low-lying limestone, probably laid down in the Tertiary period. TCI has a tropical climate with north-easterly trade winds. There are no fresh water
rivers or running streams, but brackish water bodies and ocean holes are common. Natural habitat disturbances include fires and hurricanes.

2.5.2 Origins of the flora
It is believed the Turks and Caicos Islands were never connected to other islands in the Great Bahama Bank. Hurricanes, water, birds and humans are key dispersal vectors by which plants arrive on the islands. Only species which can survive in the low elevations, high temperatures, occasional droughts and salty winds will thrive on these islands. (Correll and Correll 1982)

2.6 History of TCI
Understanding how and when invasive plants arrived on the islands requires some research into the history of TCI. Disturbances from over a century ago can affect invasions today (Von Holle and Motzkin 2007). Investigating likely arrival times of the focal species is outside the bounds of this study, but this brief historical overview shows the immense amount of trade migration TCI has experienced.

2.6.1 Overview
The Taino peoples were probably the first colonisers of TCI. It is likely they arrived from Hispaniola around 750 AD and farmed and fished on the islands for 800 years. Their slash and burn agriculture would have changed the vegetation, encouraging resilient species (Correll and Correll 1982). In 1492, Colombus is thought to have landed in TCI and the colonial slavery era began. Soon the islands were depopulated as the Spanish exported indigenous people as slaves. The following era involved extensive shipping and pirate activity along with the establishment of an international salt trade from Salt Cay and Grand Turk. The late 1700s saw the establishment of plantations by loyalists from Florida who grew cotton and sugarcane. The triangular trade route between West Africa, Europe and the Caribbean provided many opportunities for the introduction of invasive plants, and this is reflected in the fact that three of the focal plants here are native to Africa. Bermudian salt-rakers and Loyalist plantation owners cut down much of the dry tropical forest and so most vegetation on TCI is secondary.
2.6.2 Disturbance on each island

Each of the nine islands surveyed had a different history of human disturbance which will have affected the invasives found there (Appendix 1: Table 2). Grand Turk and Salt Cay had particularly heavy disturbance during the salt industry era. Along with South Caicos these three islands have the most feral grazers. Providenciales, a tourist hotspot, was more recently developed and is now the most populated island (Table 1).

Table 1: Human populations on the nine islands surveyed

<table>
<thead>
<tr>
<th>Island</th>
<th>Human population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Providenciales</td>
<td>24 348</td>
</tr>
<tr>
<td>Grand Turk</td>
<td>5 718</td>
</tr>
<tr>
<td>North Caicos</td>
<td>1 537</td>
</tr>
<tr>
<td>South Caicos</td>
<td>1 118</td>
</tr>
<tr>
<td>Middle Caicos</td>
<td>307</td>
</tr>
<tr>
<td>Salt Cay</td>
<td>114</td>
</tr>
<tr>
<td>Big Ambergris</td>
<td>90*</td>
</tr>
<tr>
<td>Little Ambergris</td>
<td>0</td>
</tr>
<tr>
<td>East Caicos</td>
<td>0</td>
</tr>
</tbody>
</table>

* fluctuates due to holiday-makers

2.7 Current political situation

Corruption in the TCI government under Michael Misick (Premier between 2006 and 2009) was uncovered in 2009. Crown land had been unlawfully sold to developers during this period. In March 2009, the Queen suspended self-government and gave her representative, Governor Gordon Wetherell, power to govern for the next two years. Unfortunately this political situation had a negative impact on the financial situation of TCNT. In addition, much building work on intact habitat took place under Misick’s government. In August 2009, the governor announced he would “make a clean break from the mistakes of the past by establishing a durable path towards good governance, sound financial management and sustainable development” (UK at the UN 2009). There is hope that this political change will help future conservation in TCI.

2.8 Biodiversity threats and conservation work in TCI

2.8.1 Development

The most immediate threat to biodiversity has been habitat conversion for development, which has proceeded despite national laws and international
conventions. For example there have been plans for construction on East Caicos adjacent to the RAMSAR site, and a causeway between East and South Caicos. This is likely to result in direct destruction of reef habitat, increased sedimentation loads and will open up East Caicos to further human impacts (Procter and Fleming 1999).

2.8.2 Climate Change
These low lying islands are particularly vulnerable to the sea level rise predicted with climate change. Extreme weather events such as hurricanes may increase in frequency. The difficultly in predicting such climate changes make predicting future distributions of invasive plants challenging. The competitive interactions between plants are likely to change, with increased CO$_2$ and temperature favouring certain species over others. Climate change may facilitate invasive plant growth as found in an experiment by Smith et al (2000), but responses will be species and site specific.

2.8.3 Current conservation in TCI
Terrestrial conservation in TCI is managed by the Turks and Caicos National Trust (TCNT), founded in 1992 and DECR. Kew has been working with TCNT for seven years providing plant conservation expertise. TCNT owns a number of sites and runs an education centre in Middle Caicos with education boards on native and invasive species. In a recent conference on invasive species, DECR stated there were 26 known invasives in TCI. DECR often has invasive animals brought in for identification, but responsibility for phytosanitary laws falls to the Department for Environmental Health.

3. METHODS
Fieldwork was carried out over seven weeks between 11$^{th}$ May and 27$^{th}$ June 2009.

3.1 Habitat preference data
To collect data on the environmental variables associated with presence of each invasive plant, the following method was developed. During pilot transects at Wild Cow Run and Conch Bar on Middle Caicos, different transect lengths were trialled. Transects 400 m in length with 50 m intervals were chosen because they gave a good representation of overall presence and did not traverse too many different habitat types. Starting transects from randomly generated points to avoid spatial
autocorrelation was tested but deemed too time-consuming since accessing the random points was very difficult. Transects had to be chosen non-randomly, but spatial autocorrelation was minimised by allocating transects as evenly as possible over the range of habitats and disturbance levels (Appendix 2: Figure 1, 2).

Sixty eight transects were walked and presence/absence points were recorded for the five species *C. equisetifolia, L. leucocephala, J. fluminense, R. communis* and *S. taccada*. A 5 x 10 m plot was surveyed, centred on the path, with the longest edge perpendicular to the path. Presence was recorded if a focal species was rooted in the plot. Other non-native plants that were known to be invasive elsewhere were noted. Additional presence points were collected in a separate database in areas of interest whilst travelling between transects.

A handheld computer (Fujito-Siemens N560) with in-built GPS was used to record data points and measure the 50m distance between assessment points. Environmental variables were recorded at every point. Plots were classified as heavily disturbed, partially disturbed or intact according to the level of anthropogenic disturbance, not natural disturbance such as wave action on the coast. Habitat type was classified as one of nine types based on the definitions agreed with the UKOTs team at Kew (Appendix 1: Table 3).

3.1.2 Data Analysis

3.1.2.1 Maps and Maxent

All maps were projected using the UTM 1984 19N projection. GPS coordinates of assessment points were transferred to ArcMap (ArcGIS 9.3) and overlaid on a baseline aerial photo of the islands. Maps of roads, coastlines and settlements were digitised by tracing from aerial images in Google Earth 5.0, zoomed to 500 m altitude. The resulting kmz files were converted to shapefiles and imported into ArcMap. Distances from each assessment point to the nearest road, coast and settlement were queried in ArcMap and converted to rasters for use with MaxEnt.

Maximum entropy modelling was used to predict suitable habitat for the five focal non-native plants *C. equisetifolia, L. leucocephala, R. communis, S. taccada* and *J. fluminense* using Version 3.3.1 of MaxEnt software. The habitat in which a species
can persist was represented as a probability distribution over the study area, with all probabilities summing to one. All recorded presence points of the species were used, not just those collected on transects. This was preferable to using a presence-absence modelling technique since the dataset would have been smaller. Table 2 shows predictors used to create ecological niche models for each species.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Source and date</th>
</tr>
</thead>
</table>
| Distances to coasts, roads and settlements | Google Earth digitisation and ArcMap calculations  
| Digital elevation model         | www.ersdac.or.jp/GDEM/E/index.html                   
| NDVI                            | Landsat ETM+ September 14 December 2001             |
| Soil index (Raw Thermal IR Band 6) | Landsat ETM+ September 14 December 2001           |

Band 6 is thermal infrared radiation which indicates the different amounts of heat emitted by different rock types and soils. NDVI (Normalised Difference Vegetation Index) was obtained from Royal Botanic Gardens, Kew GIS unit, where it had been calculated from spectral reflectance measurements using Equation 2:

\[
NDVI = \frac{(NIR - RED)}{(NIR + RED)}
\]

Equation 2: NDVI formula, where RED is red and NIR is near-infrared spectral reflectance.

Spectral reflectances are ratios of reflected to incoming radiation in each spectral band. They relate directly to photosynthetic capacity of plants so we used this as a measure of vegetative cover. High values indicate a dense vegetative cover whereas low values are typically bare ground or water bodies.

Predictors that may be autocorrelated were retained in the model (Band 6 and NDVI, distance to roads and distance to settlements) to maximise number of predictors available and therefore maximise the chance of predicting the realised niche. It is recognised that this may bias the model.
Grids were all at a resolution of 30 x 30 m. Most presence points were at least 50 m apart due to the method of transect sampling. However points that fell within the same grid cell were deleted before analysis to avoid overrepresentation in the model. Sampling bias will exist since some habitats were sampled more than others, for example near roads due to accessibility.

A random 25% of the presence points were test data with the remaining 75% as training data. The recommended default values were used for convergence threshold (0.00001), maximum number of iterations (500) and max number of background points (10 000). Cross-validation involved four replicates with each 25% of the presence points being used in turn. Models in which the relative contributions of each environmental predictor differed significantly between cross-validation replicates, were not considered robust and were not used (for full models and cross-validation results see Appendix 2). Binary maps were created using minimum training presence as a threshold. The output rasters were converted to shapefiles in order to overlay predicted suitable habitat for invasive and endemic plants.

3.2 Impact of *Casuarina equisetifolia* on native plant communities

After a pilot study at Long Bay, Middle Caicos on 13\textsuperscript{th} May, the following method was formulated. A 10 x 10 m plot invaded by *C. equisetifolia* and an adjacent plot uninvaded by *C. equisetifolia* were surveyed. Plot size was chosen as a rectangle under which *C. equisetifolia* had an influence (through shade, roots or needle drop) and a matching sized area out of this influence. Criteria for plots out of *C. equisetifolia* was at least 5 m from the nearest *C. equisetifolia* plot or 1 m from the edge of needle cover. Plots were paired to be similar in as many variables as possible except the influence of *C. equisetifolia*, for example by being the same distance from the sea or road. Thirty pairs of plots were surveyed across Middle and North Caicos in a range of habitat and disturbance types.

All plant species rooted in the plot were identified to species level and percentage cover of each was recorded to the nearest 5%. The species list was separated into native and non-native according to Correll and Correll (1982) and only native species were used in analysis. Other variables recorded were location, habitat, overall
invasion level, soil type, percentage canopy cover, canopy height and percentage ground cover.

3.2.1 Data analysis:
Native species richness in plots invaded and uninvaded by *C. equisetifolia* was compared using a paired t-test. Species richness does not take evenness into account, whereas a diversity index such as Simpson’s would. However for the purposes of this analysis, species richness was adequate to show invasive species impact. A general linear model was used to test the relative influences and possible interactions between effects of disturbance level, habitat and *C. equisetifolia* invasion on native species richness.

3.3 Resident awareness survey
One hundred structured interviews were conducted face-to-face using opportunistic sampling. This strategy was used because it was not possible to get a complete list of the registered residents and select randomly.

Participants were shown four A4 laminated photos of the following trees: *Leuceana leucocephala, Tamarindus indica, Casuarina equisetifolia* and *Pinus caribaea* var. *bahamensis* (Appendix 1: Questionnaire photos). The two non-invasive plants were chosen to provide a comparison with the invasive plants. *Tamarindus indica* is a naturalised tree from Africa and India with a fruit that is popular to eat. *Pinus caribaea* var. *bahamensis* (Caicos pine) is endemic to the Bahama archipelago and threatened by an invasive scale insect. The Caicos pine has been the focus of a recovery project which involved awareness-raising materials and school visits. Ignorance of the identity of the plants was feigned by the interviewer to avoid seeming to test the participant. The questions were presented as a chance for the interviewer to learn about the local plants. Small cultivated papaya plants were given as gifts to the respondents.

The questionnaire was designed to investigate what people know and have observed about *C. equisetifolia* and *L. leucocephala* and how these plants affect peoples’ lives (Appendix 1: Questionnaire form). Participants were asked if they recognised the plant, if they had seen a change in the numbers of the plant over the time they had
lived here, whether they thought the plant belonged in TCI and if they used the plant. In addition to this quantitative data, qualitative data on uses, positive and negative qualities of the plants was compiled. Only residents were interviewed. Demographic data were collected at the end of the interview, including age, sex, birthplace, country of residency and length of residency in TCI. Participants were asked if they had visited the conservation centre in Middle Caicos, which contains educational boards on invasive plants.

A pilot was carried out in Bambarra, Middle Caicos on 11th May, to check if the phrasing of the questions and quality of the photographs was clear. A data recording sheet and coding system was created in Excel for use on the handheld computer. A lower age limit of 12 years old was used after having an informative chat about the plants with a 14 year old. Samples of 50 people from North and Middle Caicos and 50 people from Providenciales were interviewed. North and Middle Caicos populations were combined because they are small, rural and linked by a causeway. This also allowed an even rural-urban comparison.

3.3.1 Data analysis:
Chi-squared tests were used to compare responses between the four plant species. Additional qualitative information on uses, positive and negative qualities and reasons for increases or decreases in plant numbers was recorded.

4. RESULTS
All five focal species were observed, with *C. equisetifolia, L. leucocephala* being recorded in greatest abundance.

4.1 MaxEnt predictions of suitable habitat
MaxEnt was used to predict areas of suitable habitat for *C. equisetifolia, L. leucocephala,* and all invasive plants together based on environmental predictors. All presence points were used, not just those collected on transects. This gave a total of 211 presence points which were divided between species as shown in Table 3.
Full models and cross-validation models were created (Appendix 2: Tables 3-8) and the contribution of each environmental predictor was compared across replicates. For *J. fluminense*, *R. communis* and *S. taccada* the contributions of environmental predictors varied considerably between replicates. These three species had 20 presence points or fewer, which causes problems when the data is split into test and training, because both datasets become very small (e.g. for *R. communis*, 2 points for test and 5 for training). It is possible to use a jacknife test method for small sample sizes (Pearson *et al* 2007), but this was not pursued as these small samples were not considered representative enough to create meaningful models.

Models for *C. equisetifolia* and *L. leucocephala* performed well due to the number of data points. The four replicates used in cross-validation were not significantly different in the ranks of the environmental predictors. After cross-validation, another model was run with 25% training data and this is the final model presented here. All environmental predictors contributed to the model so all were retained. Test and training AUC values were both over 0.75 so the models are considered useful.

Distance to nearest road was the predominant contributing factor for predicting presence of *C. equisetifolia*, *L. leucocephala* and all species together (Figure 4, Appendix 2: Figures 4-8). This was closely followed by distance to nearest north coast for *C. equisetifolia* habitat. The effect of distance to roads may have been exaggerated, since 33% of transect presence points were alongside a road which is probably more than would have been if transects had been chosen by randomly selecting points on the map.

Table 3: Number of presence points used for each species

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of points</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Casuarina equisetifolia</em></td>
<td>102</td>
</tr>
<tr>
<td><em>Leucaena leucocephala</em></td>
<td>71</td>
</tr>
<tr>
<td><em>Scaevola taccada</em></td>
<td>20</td>
</tr>
<tr>
<td><em>Jasminum fluminense</em></td>
<td>11</td>
</tr>
<tr>
<td><em>Ricinus communis</em></td>
<td>7</td>
</tr>
</tbody>
</table>
Figure 4: Contributions of each environmental predictor towards predicting suitable habitat for *C. equisetifolia*, *L. leucocephala* and all five invasive plants together.

Figure 5: Contributions of each environmental predictor towards predicting suitable habitat for *C. equisetifolia*, *L. leucocephala* and all five invasive plants together without roads.
When distance to nearest road was removed from the model, distance to nearest settlement contributed most to predicting suitable habitat for all invasives together, followed by distance to north coast (Figure 5). Distance to nearest settlement contributed 62.5% to the model predicting suitable habitat for *L. leucocephala*. Distance to west and north coast were the most important predictors for *C. equisetifolia* when roads were omitted from the model.

4.1.1 Cumulative maps
Predicted suitable habitats for *C. equisetifolia* and *L. leucocephala* are shown on the following cumulative maps generated using probability outputs (Figures 6, 7, 8). The locations of sampling points used for MaxEnt shows that the predictions were based on a fairly even spread of sample points across the islands (Appendix 2: Figure 3).

Grand Turk has proportionally the largest area of suitable habitat for *C. equisetifolia*. Other highly suitable habitat included Salt Cay and the roads of North and Middle Caicos. *L. leucocephala* had a larger area of predicted suitable habitat compared to *C. equisetifolia*. Providenciales was the island with most suitable habitat for *L. leucocephala*, particularly in the eastern area with more settlements. The roads and settlements of North and Middle Caicos also were highly suitable habitat.

Grouping all five invasive species together showed all islands except Little Ambergris Cay had significant areas that were highly suitable for one or more of the invasives. Grand Turk had proportionally the largest area of highly suitable invasive plant habitat, followed by Providenciales. Areas inhabited by humans tended to be predicted as highly suitable for invasive plants. Big Ambergris Cay was the only island with a significant area of highly suitable habitat but no invasive plants currently present. Asian sword ferns (*Nephrrolepis multiflora*) plants were found under the Sporting Club staff canteen during the visit. These are known to be invasive in Florida (Langeland 2001) and have since been destroyed as a precaution against further spread.
Figure 6: Probability distribution of predicted suitable habitat for *C. equisetifolia* in the Turks and Caicos Islands based on a MaxEnt model.
Figure 7: Probability distribution of predicted suitable habitat for *L. leucocephala* in the Turks and Caicos Islands based on a MaxEnt model.
Figure 8: Probability distribution of predicted suitable habitat for all five focal invasive plants in the Turks and Caicos Islands based on a MaxEnt model.
4.2 Influence of disturbance on presence of invasive plants

Over 68 transects, a total of 544 assessment points were recorded with 66 presence points observed for the five focal species *C. equisetifolia*, *L. leucocephala*, *S. taccada*, *J. fluminense* and *R. communis*. Habitat types and disturbance categories were sampled as equally as possible (Appendix 2: Figures 1, 2).

Over all invasive species observed, there were more found in anthropogenic habitats than any other habitat type. There were more invasive plants in heavily disturbed areas (Figure 9). Even intact areas are not free of invasives. Intact areas with invasive species included Three Mary Cay (North Caicos), Wheeland Salina (Providenciales), Haulover Point Beach (Middle Caicos), West Coast (East Caicos) and Flamingo Pond Middle Caicos).

![Figure 9: Number of presence and absence points in different disturbance levels](image)

A one-way factorial analysis of deviance was used to test the effect of disturbance level on proportion of invasive plants present. The explanatory variable was ordinal (disturbance levels high, partial and intact). The response variable was proportional and overdispersion was present, so a quasibinomial error structure and logit link function were used (Crawley 2007). Disturbance had a highly significant effect on
presence of invasive plants (Table 4). Back transforming the logit coefficients to give means showed presence was six times more likely in highly disturbed habitats and three times more likely in partially disturbed compared to intact habitats, which reflected general observations (Photos 8 and 9).

Table 4: Effect of disturbance on proportion of points with an invasive plant present

<table>
<thead>
<tr>
<th>Disturbance level</th>
<th>Logit coefficient</th>
<th>P value</th>
<th>Mean proportion present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-1.17</td>
<td>&lt;0.01 ***</td>
<td></td>
</tr>
<tr>
<td>Intact</td>
<td>-2.10</td>
<td>&lt;0.01 **</td>
<td>0.04</td>
</tr>
<tr>
<td>Partial</td>
<td>-0.82</td>
<td>0.09 .</td>
<td>0.12</td>
</tr>
<tr>
<td>High</td>
<td>0</td>
<td>-</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Photo 8: *L. leucocephala* in disturbed habitats on Providenciales

Photo 9: *C. equisetifolia* and *S. taccada* in disturbed habitats on Providenciales
4.3 Impact of *Casuarina equisetifolia* on native species richness

A total of 83 plant species were recorded over 60 paired plots, including 76 native species which were used in the following analysis.

4.3.1 T-test on species richness

There was a significant difference in species richness of native plants in plots invaded and uninvaded by *C. equisetifolia* (Paired t-test with equal variances, $t=5.08$, $df=29$, $p<0.05$). As shown in Figure 10, native species richness in invaded plots was significantly lower than uninvaded plots.

![Box plot of native species richness in plots invaded and uninvaded by *C. equisetifolia*](image)

**Figure 10: Box plot of native species richness in plots invaded and uninvaded by *C. equisetifolia***

The difference between the dense varied vegetation in uninvaded plots and the thick mat of needles with little vegetation in invaded plots can be seen in photos 10 and 11.
4.3.2 General Linear Model for factors affecting native species richness

Other factors aside from invasion by *C. equisetifolia* will have varied between plots, such as disturbance level and habitat type. The relative influence of each of these factors on native species richness was investigated using a general linear model. The response variable was count data, so a Poisson error distribution was used. The model was checked for overdispersion, which was not present. The maximal model included all three categorical explanatory factors, the three way interaction term and three two way interactions. Simplification was carried out using a stepwise method (Crawley 2007).

No interaction terms were significant. Habitat type (dune scrub, dune thicket, limestone scrub or limestone thicket) was removed from the model because it caused an insignificant increase in residual deviance (Chi$^2$, df=3, p=0.95). Disturbance level (high, partial or intact) was removed on similar grounds (Chi$^2$, df=2, p=0.08) (Appendix 2: Table 2). Whether a plot was invaded or uninvaded by *C. equisetifolia* was the only significant factor that best explained native species richness (Table 5). Residuals were checked for normality and appeared normal (Appendix 2: Figures 3, 4, 5, 6). Disturbance may have been important if sampling had been more equal between disturbance levels. (46 were from partially disturbed areas, 7 from heavily and 7 from intact).
Table 5: Minimal adequate model from log-linear model with Poisson errors on non-orthogonal count data. Response variable: native species richness in 60 plots

<table>
<thead>
<tr>
<th>Explanatory variable</th>
<th>Coefficient</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2.21</td>
<td>&lt;0.01 ***</td>
</tr>
<tr>
<td>Uninvaded plot</td>
<td>-0.44</td>
<td>&lt;0.01 ***</td>
</tr>
<tr>
<td>Invaded plot</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>

The following 26 species were never found under *C. equisetifolia*, and may grow poorly or not at all in the presence of these invasive trees (Table 6). *Encyclia caicensis*, an orchid endemic to TCI was observed once growing in an uninvaded plot, but never under *C. equisetifolia*. 42 species were found in both types of plot and 9 species were found only in invaded plots (Tables 7 and 8).

Table 6: Species found only in uninvaded plots (23 native species, 3 non-native species shown in bold)

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of plots in which present</th>
<th>Average percentage cover</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Antirhea myrtifolia</em></td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td><em>Argythamnia lucayana</em></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><em>Boerhavia erecta</em></td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><em>Borreria brittonii</em></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><em>Borrichia frutescens</em></td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td><em>Catesbaea foliosa</em></td>
<td>2</td>
<td>31</td>
</tr>
<tr>
<td><em>Cephalocereus bahamensis</em></td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><em>Chamesyce blodgettii</em></td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><em>Cladium jamaicense</em></td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><em>Coccoloba diversifolia</em></td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td><em>Conocarpus erectus</em></td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td><em>Conyza canadensis</em></td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td><em>Cordia bahamensis</em></td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><em>Crossopetalum rhacoma</em></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><em>Encyclia caicensis</em></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><em>Helicetres jamaicensis</em></td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td><em>Iva imbrata</em></td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><em>Languncularia racemosa</em></td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><em>Passiflora cuprea</em></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><em>Phyllanthus epitphyllanthus</em></td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td><strong>Portulaca oleracea</strong></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><em>Randia aculeata</em></td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><em>Schoenus nigricans</em></td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><em>Solanum bahamense</em></td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td><em>Tillandsia utriculata</em></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Wedelia bahamensis</strong></td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>


### Table 7: Species only found in invaded plots (9 native species, 1 non-native shown in bold)

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of plots in which present</th>
<th>Average percentage cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caesalpinia bonduc</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Canavalea rosea</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Metastelma sp.</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Passiflora suberosa</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Phyla nodiflora</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Sabal palmetto</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Salmea petrobioides</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><strong>Scaevola taccada</strong></td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Smilax havanensis</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Stachytarpheta fruticosa</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

### Table 8: Species found in both uninvaded and invaded plots (42 native species, 2 non-native)

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of plots in which present</th>
<th>Average percentage cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambrosia hispida</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Argusia gnaphalodes</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Borrichia arborescens</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>Bourreria ovata</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Bursera simaruba</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Casasia clusifolia</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Cassia lineata</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Cassytha filiformis</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Cenchrus sp</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Cephalocereus millspaughii</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Chloris sagraeana</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Chrysobalanus icaco</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Coccoloba uvifera</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Coccothrinax argentata</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Corchorus hirsutus</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Croton discolor</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Erithalis fruticosa</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Ernodea littoralis</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Euphorbia abbreviata</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Euphorbia mesembranthemifolia</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Guapira discolor</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Gundlachia corymbosa</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>Ipomoea alba</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>Ipomoea pes-caprae</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Ipomoea violacea</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Lantana bahamensis</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td><strong>Leucaena leucocephala</strong></td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Metastelma eggersii</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Metopium toxiferum</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Opuntia bahamana</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Panicum maximum</strong></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Passiflora pectinata</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Pentalinon luteum</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Plant Name</td>
<td>Score</td>
<td>Rank</td>
</tr>
<tr>
<td>----------------------------</td>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>Rhachicallis americana</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Scaevola plumieri</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>Sesuvium portulacastrum</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>Smilax auriculata</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Sporobolis virginicus</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Sporobolus domingensis</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Suriana maritima</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Thrinax radiata</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Turnera ulmifolia</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Uniola paniculata</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Vernonia arbuscula</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

4.4 Binary maps showing suitable habitat of invasive and endemic plants

Binary maps were created from the cumulative maps made using MaxEnt minimum training presence thresholds, which were 0.036 for *C. equisetifolia*, 0.006 for *L. leucocephala* and 0.0275 for all invasives. These maps were overlaid on binary maps of predicted suitable habitat for three endemic plants (*Argythamnia argentea*, *Limonium bahamense*, *Encyclia caicensis*) (Williams 2009, unpublished data). Both invasive and endemic plant habitats were predicted using the same field survey and data analysis methods, so the areas are directly comparable. All binary maps are shown in Appendix 3.

*C. equisetifolia* had suitable habitat on all islands, but predominantly on Big Ambergris Cay, Salt Cay, South Caicos and Grand Turk. These islands also had the largest overlap with endemic suitable habitat. *L. leucocephala* had suitable habitat on all islands except Grand Turk and Salt Cay. Largest areas of suitable habitat for *L. leucocephala* were predicted for Providenciales, North Caicos and Middle Caicos. Overlap between *L. leucocephala* and the three endemics suitable habitat was mostly on South Caicos, Big Ambergris Cay and small areas of Middle and North Caicos.

When all five invasives were grouped together, Big Ambergris Cay, Grand Turk and Salt Cay come out as areas of highest concern due to overlapping invasive and endemic habitats. Invasive plants are likely to pose a significant threat to endemic plants on these islands. The central region of South Caicos, Wild Cow Run, Three Mary Cays (Middle Caicos) and south east North Caicos are also areas of concern. Islands without significant overlap are Providenciales (due to lack of endemics), Little Ambergris Cay, (due to small non-overlapping suitable habitats), and East Caicos (lack of endemics).
4.5 Public awareness survey
From 100 social surveys, both qualitative and quantitative data were obtained. Fifty males and fifty females were interviewed. 60% of respondents were born in TCI and the average residency was 29 years. 18% of people interviewed had visited the conservation centre.

The plants were familiar to most people, 93% of respondents having seen the invasive plants and 55% being able to name them. More people had noticed an increase in the invasive plants compared to the non-invasive plants than would be expected if there was no difference in the changes in these populations. However the origins of the plants were little known since only three people reported *C. equisetifolia* did not belong in TCI. Six people reported that *L. leucocephala* did not belong in TCI. Five of these people were not born in TCI and had seen the plant in their birthplace country. People were equally likely to report native and non-native plants as belonging in TCI (Pearson's Chi-squared test, X-squared = 4.60, df = 3, p=0.203).

The proportion of people who noticed an increase in each of the plants varied between species (Fisher's Exact Test for Count Data, p<0.05, Figure 11). More people than expected noticed an increase for the two invasive species *Leuceana leucocephala* and *Casuarina equisetifolia* whereas fewer than expected noticed an increase for *Tamarindus indica* and *Pinus caribaea* var. *bahamensis*. The following anecdote from Carlin Forbes (Bambarra resident, 80 yrs old) on the spread of *C. equisetifolia* is of particular note. “When I was a boy there was only one on Bambarra beach, Middle Caicos, now there is a long line”.
Fifty-six percent of respondents stated a use for *L. leucocephala*, and 31% for *C. equisetifolia*. The number of people that stated a use for each plant did vary by species (Pearson's Chi-squared test, $X^2 = 34.4966$, $df = 3$, $p < 0.05$). More than expected used *T. indica* and fewer than expected used the other plants. The uses stated were not all activities that the respondents performed personally. One caveat of the questionnaire was people often reported uses from the past. Uses are summarised below.

- **Leuceana leucocephala:** Fuel, seeds eaten, made into necklaces, lobster pots, oil used, children play with the seeds, collages, sling shots, high protein food for goats and cows (more in the past), make into a drink to lower blood pressure, play the seeds as a whistle
- **Casuarina equisetifolia:** Christmas trees, boat masts, fertilizer, hair oil, shade, lumber, whips

Where time allowed further questions relating to the positive and negative qualities of the plants were asked. The responses for the two invasive species are reported here to give an indication of how an invasive control program would be accepted by the public.
Both *L. leucocephala* and *C. equisetifolia* were described as beautiful. *L. leucocephala* was used as cattle feed in the past, so was previously viewed more positively. Now the negative aspects of its aggressive growing habit are recognised and people try to chop it down in their backyards but it grows back.

*C. equisetifolia* was valued by some respondents for its whistling sound in the breeze, soft mat of needles and shade. Some stated that it helped absorb the energy of hurricanes and held the beach together. In contrast one respondent mentioned that they fall down easily in hurricanes and the government have advised chopping them down when a hurricane is predicted to prevent damage.

The negative invasive properties were only mentioned twice, in the following quotes about *C. equisetifolia*: “It is from the Bahamas, and it is spreading here, plants can’t grow under its shade” (Lynne, USA, lived here 3.5 years). “Not many soft-leaved trees can grow under it because the needles don’t mulch” (Richard, Jamaican, lived in TCI for 16 years).

Significant differences in responses were seen between Providenciales and Middle and North Caicos. For example, 35% of people in Providenciales used a recognised name for the plant compared to 71% in Middle and North Caicos (Chi squared = 42.5, df = 1, p< 0.01). Only 18% of respondents in Providenciales reported a use of the plants, compared to 48% of people on Middle and North (Chi squared = 39.7, df = 1, p<0.01). No other significant effects of demographic variables on responses were found.

4.6 Further non-native species observed

Non-native species observed in TCI and known to be invasive elsewhere were recorded (Table 9). Compiling this type of list is a good start in developing an early warning system for potential invaders.
Table 9: Non-native species with invasive potential that were observed in the Turks and Caicos Islands and examples of countries in which they are native and invasive

<table>
<thead>
<tr>
<th>Species</th>
<th>Native to</th>
<th>Invasive in</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pennisetum setecetum</em></td>
<td>Middle East</td>
<td>Hawaii, Arizona</td>
<td>Poulin <em>et al</em> 2005</td>
</tr>
<tr>
<td><em>Cryptostegia grandiflora</em></td>
<td>Madagascar</td>
<td>Hawaii, Mauritius, Australia, SE Asia</td>
<td>GISD 2009</td>
</tr>
<tr>
<td><em>Calotropis procera</em></td>
<td>India, Iran, Africa</td>
<td>Hawaii, Australia, Thailand, Vietnam, Seychelles</td>
<td>HEAR 2009</td>
</tr>
<tr>
<td><em>Kalanchoe daigremontiana</em></td>
<td>Madagascar</td>
<td>USA, Puerto Rico, Hawaii</td>
<td>Herrera and Nassar 2009</td>
</tr>
<tr>
<td><em>Azadirachta indica</em></td>
<td>India</td>
<td>Caribbean, Brazil</td>
<td>HEAR 2009</td>
</tr>
<tr>
<td><em>Nephrolepis multiflora</em></td>
<td>Tropics of Africa/Asia</td>
<td>Mascarene Islands, SE USA</td>
<td>Weber 2003</td>
</tr>
<tr>
<td><em>Tamarix canariensis</em></td>
<td>Central Asia and Middle East</td>
<td>Australia, USA, Mexico, South Africa</td>
<td>GISD 2009</td>
</tr>
<tr>
<td><em>Sansevieria hyacinthoides</em></td>
<td>Africa</td>
<td>Florida</td>
<td>Invasive.org 2009</td>
</tr>
<tr>
<td><em>Schinus terebinthifolius</em></td>
<td>Northeastern Argentina, Paraguay and Brazil.</td>
<td>Cuba, Fiji, Bermuda, Israel, Mauritius, New Zealand</td>
<td>GISD 2009</td>
</tr>
<tr>
<td><em>Sesbania grandiflora</em></td>
<td>Indo-Malaysia</td>
<td>USA, Pacific islands</td>
<td>HEAR 2009</td>
</tr>
</tbody>
</table>

4.7 Additional outputs

In addition to the study, educational materials were produced for the Turks and Caicos National Trust. These included posters on four of the most abundant invasive plants to encourage recognition (Appendix 2: Figure 9) and a series of postcards of photographs of the endemic plants to promote awareness and respect of the native flora amongst tourists. A number of newspaper and magazine articles in the local and international press were written about the project. A focus group discussion with staff from the Department for the Environment and Coastal Resources was held at the end of the fieldwork period. The project results so far were used as a basis for discussing possible control programs, awareness campaigns and the history of the origin of the non-native species.
5. DISCUSSION

5.1 Status of invasive plants in TCI
Overall invasive plants present a significant threat to native biodiversity in TCI. However there is real opportunity to mitigate this threat and the situation has not reached the same magnitude as on some islands, such as the Galapagos Islands (Mauchamp 1997).

*C. equisetifolia* and *L. leucocephala* were the most abundant invasive plants found. New invasive species were emerging, some of which had escaped from landscaped gardens, such as *Pennisetum setecetum*. The most widespread plants were *C. equisetifolia* and *L. leucocephala*, perhaps because they were introduced much earlier than the other three focal species. However there is a possibility that *C. equisetifolia* and *L. leucocephala* were recorded in greater number because of their higher conspicuousness. Plots were examined thoroughly to try to avoid false absence recordings but the possibility cannot be ruled out.

*L. leucocephala* had a larger area of highly suitable habitat than *C. equisetifolia* so it may have the potential to become more widespread (although many other factors such as dispersion are not taken into account here). *L. leucocephala* was not recorded on Grand Turk or Salt Cay, probably because its ecological niche has been filled by *Acacia spp.* which are not eaten by feral grazers. Observations showed these large stands of *Acacia* provide a supporting frame for *J. fluminense* to climb on. The role of grazers is an important influence on the population of invasive plants and this would be interesting to explore further. Grand Turk and Providenciales had the largest areas of suitable invasive plant habitat, predominantly for *C. equisetifolia* and these islands also have the highest human populations (Table 1) and long histories of disturbance and trade (Appendix 1: Table 2).

Most invasive plants were found in anthropogenic habitats and heavily disturbed areas, agreeing with previous studies that show disturbance can facilitate species invasions (Meyerson and Mooney 2007, Hobbs and Huenneke 1995). Yet invasive plants were also present in some intact habitats. It appears populations of invasive plants in anthropogenic habitats provide sources of propagules that spread to naturally disturbed areas such as intact coastal dunes.
Disturbance at these sites was predominantly caused by the construction of new buildings and roads. This increases the number of propagules brought into an area, which can travel on machinery, in fill and building materials and via vehicles travelling along roads. Disturbance also removes vegetative cover, which can facilitate invasions by reducing competition (Richardson and Bond 1991) and creating bare ground for ruderal species to colonise. Trampling by people and feral grazers can create spaces for invasive plants to grow in. Most focal species were good pioneers (especially *C. equisetifolia* (Weber 2003), *S. taccada* (Manner et al 1984) and *R. communis* (Arnone and Korner 1993) so are able to colonise bare patches quickly, before other native species. Disturbance can also cause a pulse of nutrient enrichment which can increase the chances of successful invasive establishment (Richardson and Pysek 2006).

MaxEnt models showed distance to road to be the most important environmental variable in predicting presence of these invasive plants. Vehicles travelling along roads are very effective at creating disturbance and dispersing seed throughout a range of habitats (Baskin 2002). Roads encouraged population expansion of three non-native species in deciduous forest in the USA (Christen and Matlack 2009). Building roads causes habitat fragmentation and increases edge effects which can open up intact habitat to invasive propagules. Planting native species along roadside edges to create an intact barrier may reduce invasion through edges (Cadenasso & Pickett 2001).

When roads were removed from the model because of suspected sampling bias, distance to settlements became the most important factor for *L. leucocephala*. This agrees with Walton (2003) who found disturbed and artificial habitats to have the highest abundance of *L. leucocephala*. The history of *L. leucocephala* as a fodder crop means it was probably deliberately planted near settlements where people kept livestock (Shelton and Brewbaker 1994). Sites that have been cultivated tend to have higher non-native species richness (Von Holle and Motzkin 2007). For *C. equisetifolia*, distances to west and north coast were the most important predictors when roads were omitted from the model. This reflects the native niche of *C. equisetifolia* as a coastal plant which is encouraged to reproduce vegetatively when damaged by coastal disturbance (Parrotta 1993).
C. equisetifolia was associated with reduced native species diversity in its vicinity. Correlation does not imply causation and the direction of causation is not certain. It is possible that lower species richness increases the chances of successful C. equisetifolia invasion. This is where a removal experiment could prove the direction of causation, as exemplified by an experiment comparing plots in which invasive Amur honeysuckle, Lonicera maackii were present, absent and removed (Gould and Gorchov 2000). Considering additional evidence from the literature, it seems more likely that C. equisetifolia is causing reduced native species richness than vice versa. There is evidence for the allelopathic nature of C. equisetifolia needles on crop species (Jadhav and Gaynar 1995) which is probably due to high concentrations of selenium and salts and low decomposition rates (Parrotta 1993). The shade C. equisetifolia creates is thought to put dune species adapted to high light levels at a disadvantage (Marchante et al 2003). Being a nitrogen-fixing species, it is also likely to alter the nutrient cycling of the ecosystem, perhaps changing the ecological niches of native species.

The predicted suitable habitat of invasive plants did overlap with that of endemic plants, particularly on Big Ambergris Cay, Grand Turk and Salt Cay. This was mainly due to suitable habitat for C. equisetifolia, L. leucocephala, A. argentea and L. bahamense. No endemic species were found growing under C. equisetifolia. The distribution of the three endemic species was already very limited (Williams, unpublished data) and the synergistic threats of invasive plants and development threaten to reduce their range even further. There is evidence to show that losing rare species from a community can increase susceptibility to invasion (Lyons et al 2001). Not only can preventing invasions help maintain diversity, but maintaining diversity can help prevent invasions. This cyclical relationship emphasises the need for integrated conservation focused on both threatened and invasive species.

Resident surveys showed invasive plants were used, but mostly used for recreational activities, no longer as a substantial part of local livelihoods. Most people thought C. equisetifolia and L. leucocephala belonged on the islands because they have been here for longer than their lifetimes. This finding hints at a shifting baseline in the perception of what native flora is, however further data would be needed to test this hypothesis. There is also the possibility that the question “Does this plant belong in
“Does this plant grow in the Turks and Caicos Islands?” was sometimes interpreted as “Does this plant grow in the Turks and Caicos Islands?” The phrasing of this question was difficult since “native” status can be a sensitive issue. It seems that the concept of plants being introduced from elsewhere was not familiar to the majority of respondents, because they hinted the fact that the plant belonged here was obvious. Yet this lack of awareness is a more widespread problem than just TCI, and I expect the general public in many countries do not know the history of their flora.

Respondents from the more urban Providenciales had a lower awareness of flora than on rural islands. This reflects Pyle’s “extinction of experience” phenomenon, where urbanization results in homogenisation of local flora and fauna, and disconnection of humans from their environments. It is a vicious cycle where urbanisation can be the cause and effect of disconnection of humans with nature, as shown in Figure 12. Educating the urban population about the value and relevance of nature is an important step in conservation of all ecosystems (McKinney 2002, Miller 2005).

Figure 12: Concept diagram showing the “Extinction of experience” phenomenon, first described by Pyle (1978). The linking arrows reflect a possible set of causes and effects, but each factor can contribute independently to a loss of biodiversity and other links are also likely to be present.

5.2 Implications for conservation

5.2.1 Control programs

Justification of a control programme depends on evidence for the negative impact of an invader. Only impact of C. equisetifolia was studied here, but negative impacts for
the other species were found in the literature. Impact assessments specific to TCI are preferable since invasives can have large effects in some areas and minimal effects in others (Byers et al 2002).

The likelihood of eradication success is highly scale dependent. A review of eradication efforts in California showed eradications were almost always successful for less than one hectare, but extremely unlikely for over 100 hectares (Baskin 2002). From the small number of observations of S. taccada, R. communis and J. fluminense it appears removal may be possible. S. taccada has been recommended for removal in the Bahamas (BEST Commission 2003). R. communis and J. fluminense could be controlled through herbicide application or hand removal, targeting waste grounds and roadsides.

Considering the wide extent of C. equisetifolia and L. leucocephala and the positive values and uses some people have for the plants, it appears control of the invading frontier and removal of outliers in the population would be better than attempting large scale eradication. Physical labour has been a successful control strategy in the past (Simberloff 2009), having been used to create new employment opportunities (South Africa’s Working for Water Program), or give work to diverse voluntary groups such as students, convicts and paying ecotourists. One disadvantage of control as a management option is the high recurring costs. However, if significant economic benefits will result, such as improved flood protection, the costs will be recovered fairly quickly (Zavaleta 2000). The key to a successful control programs are sufficient resources and persistence, cooperation enforcement, well studied target species and rapid responses to early warning of invasion (Simberloff 2009).

Weighing up the costs and benefits of a control strategy is a prerequisite to deciding if a control programme is worthwhile. Table 10 outlines possible benefits and costs based on social survey results and general observations. The costs of control may not be borne by the people who benefit and the impacts on different stakeholders must be considered. In this case the benefits to the local and global community are high but there will be significant local costs. The costs of herbicide application in particular should be considered since there is evidence of significant negative effects of herbicides on native flora (Rinella et al 2009). The costs of inaction are also
important to consider (Byers et al 2002) and detailed accounting will be needed to calculate if the benefits outweigh the costs.

Table 10: Expected costs and benefits of invasive plant control and greater biosecurity in TCI at local and global scales

<table>
<thead>
<tr>
<th>Local</th>
<th>Global</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Benefits</strong></td>
<td><strong>Global biodiversity benefit</strong></td>
</tr>
<tr>
<td>• Reduced risk of negative effects on health (e.g. <em>C. equisetifolia</em> associated respiratory problems)</td>
<td>• Global biodiversity benefit</td>
</tr>
<tr>
<td>• Increased native biodiversity associated with unique identity of TCI, for example endemic plants and sea turtles are expected to benefit</td>
<td>• Fewer source pools of invasives with potential to spread to other countries</td>
</tr>
<tr>
<td>• Potential for ecotourism increased if native biodiversity retained</td>
<td></td>
</tr>
<tr>
<td>• Reduced risk of hurricane damage from falling <em>C. equisetifolia</em> trees</td>
<td></td>
</tr>
<tr>
<td>• Reduced risk of future problems of current invasives as yet unmeasured such as impacts on hydrological and nutrient cycles, facilitation of future invasions</td>
<td></td>
</tr>
</tbody>
</table>

| **Costs** | **Reduced international trade in certain landscaping plants** |
| • Direct long-term cost of control (herbicides, labour, machinery, vehicles) | • Restrictions and checks on import of fill and building materials |
| • Increased concentrations of herbicidal chemicals in environment | |
| • Reduced opportunity to use the plants (for shade, timber, landscaping) | |

Along with costs and benefits, prioritising islands for control programs will depend on feasibility, likelihood of success and permanence. Salt Cay, Grand Turk and Big Ambergris Cay had the largest proportion of overlapping endemic and invasive suitable habitat so could be high priority. However the wide extent of invasives on Grand Turk may make control too costly. Resources could be better spent on areas like Salt Cay where the island is smaller, population is lower, chances of reinvasion may be lower and endemic plants are more abundant.

5.2.2 Biosecurity

Big Ambergris Cay was the only inhabited island with no invasive plants but extensive suitable habitat, so phytosanitary checks must be kept at a maximum to prevent invasion. This would involve banning import of plants known to be invasive
elsewhere (Table 9) and encouraging passengers to check if any plant material is on their clothes or luggage. Training inspectors at airports and seaports is highly recommended (GSPC Review 2009, Pimentel et al 2005). The existing biosecurity policy should be revised to remove plants with known invasive potential from the approved planting list (specifically Antigonon leptopus (HEAR 2009) and Agave sisalana (Invasive.org 2009)). Using the precautionary principle is advisable, where in the absence of scientific knowledge on the likely harm of an invasion, it should be treated as potentially harmful and its transport restricted (Hochberg and Gotelli 2005).

Little Ambergris Cay was the only uninhabited island without invasive plants. Retaining nature reserve status and restricting access to this island should help retain this invasion free status. However if nearby Big Ambergris Cay becomes invaded, the chances of propagules reaching Little Ambergris Cay by wave dispersal would increase.

5.2.3 Habitat manipulation
Habitat could be managed to reduce its invasibility (Sheley and Krueger-Mangold 2003), as shown by the use of grazing and fire regime manipulation to control woody weed invasions in Australia (Conacher 2001). In Turks and Caicos, disturbance associated with roads was a key invasion facilitator. Encouraging development in areas already disturbed and giving protected status to important intact habitats would prevent easy entry points for invasive plants. However this approach may also require subsequent habitat restoration such as the planting of native trees that are good competitors (Funk and Vitousek 2007). It would be useful to know if the driver or passenger model is most applicable to this system to predict how far habitat manipulation will be beneficial (MacDougall and Turkington 2005).

5.2.4 Improving public awareness
The social survey results clearly showed a need for an awareness campaign. The terminology used must be sensitive to the multicultural demography of the human population, for example terms like “invasive”, “eradicate” and “non-native” can be particularly loaded if their context is misinterpreted. Educational materials should start by clearly defining what is meant by the term “invasive plant”. Discussions at community meetings could work well, as we found when presenting in Conch Bar
The results of this project have been reported to TCNT and will be shared at community meetings in September 2009 on Middle and North Caicos (Jones, M. pers. comm. 2009). The population of Providenciales is a key target since there was lower awareness here than on Middle and North Caicos. Posters for targeting schools have been produced and will be distributed by TCNT. Working with students was effective in San Lorenzo, Argentina in increasing awareness and instigating a law that only native trees could be planted in the village (Speroni et al 2003).

Distribution of information to the horticultural sector could help voluntary efforts to reduce introductions of invasive plants and encourage the use of native plants. For example, *S. taccada* could be replaced with native *S. plumieri* and the use of *Pennisetum setaceum* could be discouraged because it is highly invasive in Hawaii and Arizona (Poulin et al 2005). Burt et al (2007) found horticulturalists who were aware of invasive plants and involved in trade associations were more likely to participate in control measures.

Developing the nursery at Bambarra to grow native plants on a scale at which they could be sold commercially could be an option. This would be along the lines of the “Cayman Collection”, a range of native plants sold by a nursery in the Cayman Islands. Plants are chosen on their cultural significance, suitability for landscaping, conservation status and potential to attract wildlife. A campaign to encourage houses to be more sensitive to their landscape is also encouraged. Rather than clearing areas of land and planting non-native species, intact bush can be left by the house as a “natural garden”. With a combination of biosecurity, public awareness, native landscaping and control of the invading frontiers, the negative impact of invasive plants in TCI could be reduced.

### 5.3 Strengths and limitations of the study

#### 5.3.1 Strengths

This study has created a robust dataset on the distribution, impact and awareness of invasive plants in TCI. As such it has made a significant improvement to the scientific knowledge base which was previously limited to a few observations and anecdotal evidence. The matched pairs methodologies make the data particularly
strong, both for comparing invaded and uninvaded plots, and comparing endemic and invasive predicted suitable habitats. The study was deliberately broad to be a useful overview for TCNT. By using standardised techniques to collect GPS referenced data, long term monitoring will be possible. Using methods that can be repeated in future is important for the study to be part of the larger research picture. Additional data was collected in the field to provide datasets compatible with the Kew UKOT team databases. It is very much hoped this data and the educational materials produced will be useful for Kew and TCNT in future.

5.3.2 Limitations
5.3.2.1 Criticisms of MaxEnt
Anomalies on map outputs: The accuracy of map outputs reflects the quality of environmental predictors. The map outputs generally reflected observations in the field. There were a few anomalies of areas of land that do not exist for example small offshore islets and terrestrial suitable habitat for *L. leucocephala* in the centre of Big Pond, a submerged area. Also the new deepwater harbor on Big Ambergris Cay was not included. This was due to inaccuracies in the DEM. The accuracy of the small patches of predicted suitable habitat on Little Ambergris Cay cannot be interpreted at a fine scale, but the map shows suitable *C. equisetifolia* habitat is along the coast.

Sampling bias: Bias towards roadsides and accessible areas, as in this study, is the most common source of bias in biodiversity databases (Kadmon *et al* 2004, Phillips 2008). This project sampled a range of habitats and disturbance types fairly equally (Appendix 2: Figures 1, 2). This was to avoid leaving an identifiable subset of environmental conditions unsampled, which would fool the presence only model into thinking these areas were not suitable. However, only a very small area of East Caicos was sampled and further sampling on this island may have revealed invasive plants were more widespread than the model shows.

Transferability, climate change and future relevance: Transferability is the ability of the model to correctly extrapolate from a sampled area to an unsampled spatial area or extrapolating to another time period. It was not tested for in this study, so models should be interpreted with caution since this issue has been raised as one of the weaknesses of MaxEnt (Phillips 2008).
The issue of transferability is particularly important in judging how far into the future these maps will be relevant. These predicted areas of suitable habitat will not be valid for long because they do not predict changes over time. Global changes such as increased CO$_2$ concentrations and nitrogen deposition are predicted to favour many invasive species, including growth rates of invasive plants (Dukes and Mooney 1999, Meyerson and Mooney 2007). As low lying islands with seasonal hurricanes, the impacts of climate change on TCI are likely to be significant. The unpredictability of future climate scenarios makes predicting the spread of invasives into the future very challenging, but studies such as Roura-Pascual et al (2004) have shown it to be possible.

Limitations of the data sets: The environmental predictor grids were fairly limited in their predictive ability since the landscape of TCI is generally quite homogenous in terms of topography and geological substrate. Many layers were based on similar data, since four layers were related to coasts, roads and settlements were similar and band 6 and NDVI were calculated from similar IR bands. Band 6 was lower resolution than other layers, being originally at 60 m. The road, settlement and coast layers may be inaccurate due to the manual process of digitisation and the unknown projection accuracy of Google Earth’s mosaic images. The environmental layers used to make predictions were from dates ranging from 2000 to 2009. The road map is likely to already be outdated since road building was occurring at a rapid pace during the fieldwork period. Despite these limitations, the maps produced did reflect the general picture of the distribution of invasive plants seen in reality.

5.3.2.2 Limitations of impact study and awareness survey

In the study of *C. equisetifolia*'s impact, the extent of influence of the root system was unknown and may have had an influence on the “uninvaded” plots. Spatial autocorrelation was not considered a problem because of the paired sampling design, however it would be interesting to run a mixed effects model with transect as a random effect to compare the results with those obtained in the GLM on native species richness. The social survey sample was limited to 100 respondents over three islands. Sampling was not random and excluded the small fraction of the population who did not speak English.
5.4 Future research

Nationwide impacts of *C. equisetifolia* could be calculated if the data from invaded and uninvaded plots were converted to *per capita* effect on native species. This would then be multiplied by range size and abundance per unit area as in equation 1 Parker *et al* (1999). If further data was collected for all five focal species the impact of each could be calculated and compared. A risk assessment could be undertaken for each species along the lines of those done by Great Britain’s non-native species secretariat (Non-Native Species Secretariat 2009). This would help prioritise which invasive species should be tackled first. These risk assessment tools can be used to calculate probable costs and level of uncertainty over predictions.

Predictive suitable habitat for *S. taccada, J. fluminense, R. communis*, could be mapped if more presence points could be collected or if the method of Pearson *et al* (2007) could be used to run MaxEnt models on existing points. In general, surveying more extensively would improve knowledge of distribution and the quality of MaxEnt map outputs. Aerial surveys of the large invasive trees or coastal boat surveys of *C. equisetifolia* could help. Satellite imagery could be used to detect distribution based on habitat types typically invaded by the species (Byers *et al* 2002).

Making predictions of suitable habitat under future climate change would be extremely interesting and would involve complex modelling. Methods of introduction such as trade and tourism and patterns of dispersal could be included (Thuiller *et al* 2005, Meyerson and Mooney 2007). Investigating the impact of these plants on native flora, ecosystem processes and human welfare would also be interesting. Cost-surface analysis in ArcGIS could be used to predict future spread along pathways of least resistance such as roads. Investigating the impact of these plants on native flora, ecosystem processes and human welfare would also be interesting.

A removal experiment would demonstrate the effects of an invasive control management strategy. Invasives could be removed from a random proportion of invaded sites and the recovery of the ecosystem compared with invaded control sites (Sutherland 2006). The results of such a management trial could be recorded and shared, for example via websites such as www.conservationevidence.com or the
GISD. This has been a useful exercise for sharing knowledge on herbicide based control of Japanese Knotweed in the UK (Ford 2004). Since these plants are invasive in a large number of countries, the shared knowledge would be widely valued.

5.5 Conclusion

In conclusion, this study provides baseline data needed to start managing invasive plants in the Turks and Caicos Islands. It provides maps to help focus conservation efforts on suitable invasive plant habitat, particularly areas where endemic plants are likely to be threatened by invasive plants. The distribution of invasive plants was most influenced by the road network and to a lesser extent by settlements and coasts. Disturbance was a key facilitator of invasive plant spread and establishment. Areas invaded by *C. equisetifolia* had reduced native species richness. Although people recognised the plants, they were largely unaware of their non-native status and potential to cause negative ecological impacts.

What action results from this project will depend on resources and capacity within the wider framework of conservation in TCI. Having a good biosecurity policy is a principal recommendation, in particular banning import of plant species known to be invasive. An integrated approach that combines prevention, early detection, early control and ecosystem level management will be more effective than just focusing on control (Hobbs and Humphries 1995).

Management strategies depend on the way humans value the impacts of non-native species, which changes over time. For example, the value of *S. taccada* as a beach stabiliser or *L. leucocephala* as a fodder crop was important in the past but less so now. Some plants may be “sleeping giants” (Hobbs and Humphries 1995), in other words non-natives encouraged to grow through agriculture and horticulture now, may not appear to have negative effects, but may become invasive in future. By looking at the past and the future in this way, lessons from past invasions can provide guidance to minimise future impacts of invasive species.
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**Appendix 1: methods**

**Table 1:** Habitat classifications used in data recording, agreed with UKOTs team at Royal Botanic Gardens, Kew

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Defining characteristics</th>
</tr>
</thead>
</table>
| Limestone scrub       | Low, sparse vegetation generally (< 1.5 m) on limestone substrate  
Example locations: Near power generator, Salt Cay  
Typical species: *Reynosia septentrionalis*, *Acacia choriophylla*, *Jacquinia cayensis*, *Metopium toxiferum*, *Pithecellobium keyense*                                                                                                                                                                                                                                                                       |
| Limestone thicket     | Tall, dense vegetation forming a canopy on limestone substrate, generally over 1.5 m.  
Typical species: *Bursera simaruba*, *Bourreria ovata*, *Helicteres jamaicensis*, *Swietenia mahagoni*  
Example locations: South Caicos                                                                                                                                                                                                                                                                                                                                                      |
| Ironshore             | Coastal rock formation consisting of a hard crust of coral reef, sand and marl deposits constantly eroded by rain and surf to create hollowed solution features. (The maritime heritage of the Cayman Islands By Roger C. Smith)  
Vegetation typically small and sparse.  
Typical species: *Boerrichia arborescens*, *Strumpfia maritima*, *Rhachicallis americana*  
Example locations: Coast near Bird Rock Point, Providenciales                                                                                                                                                                                                                                                                                                                                 |
| Pineyard              | Seasonally flooded forest with honeycomb rock substrate dominated by *Pinus caribae var. bahamensis*  
Typical species:  
Palms: *Sabal palmetto*, *Coccothrinax argentata*, *Metopium toxiferum*, *Byrsonima lucida*, *Pithecellobium keyense*, *Smilax auriculata*, *Encyclia rufa*  
Example locations: Readymoney Pineyard                                                                                                                                                                                                                                                                                                                                              |
| Dune scrub            | Low, sparse vegetation generally (<1.5 m), on sand substrate.  
Typical species include: *Uniola paniculata*, *Euphorbia mesembrianthemifolia*, *Ernodea littoralis*, *Erithalis fruticosa*, |


**Ipomoea pes-caprae, Ambrosia hispida, Scaevola plumieri, Sporobolus virginicus, Acacia acuifera, Spermacoce spp.**  
Example locations: Parts of Little Ambergris Cay

| **Dune thicket** | Tall, dense vegetation generally (>1.5 m), on sand substrate.  
Typical species:  
*Coccothrinax argentea, Antirhea myrtifolia, Guapira discolour, Coccoloba uvifera, Casasia clusifolia, Thrinax radiata*  
Example locations: Central Ridge Big Ambergris Cay |
|---|---|
| **Salinas** | Brackish pools with high salt content, periodically inundated with saltwater. Silt substrate, covered by algal mats when dry.  
Typical species:  
*Salicornia perennis, Salicornia bigelovii, Suaeda linearis, Batis maritime, Conocarpus erectus, Avicennia germinans*  
Example locations: Salt Cay |
| **Anthropogenic** | Urban areas where humans have significantly altered the habitat. Dominated by asphalt, concrete and roof. (UKOTS Field Collection guide)  
Typical species:  
*Leucaena leucocephala, Casuarina equisetifolia, Scaevola taccada, Cocos nucifera*  
Example locations: Beaches Resort, Providenciales |
| **Dry tropical forest** | Mature vegetation with tall canopy dominated by trees on loam soil.  
*Bucida buceras, Siderexylon salicifolium, Lysioloma latisiliquum, Bursera simaruba*  
Example locations: Wade’s Green Plantation, North Caicos |

---

**TCI Plants Questionnaire**

*Data was filled in directly into Excel Spreadsheets on the handheld computer*

Introduction: Hello, we are working with the National Trust, studying plants. Do you have a moment to spare to talk to us about the plants and whether you have seen them? Don’t worry if you don’t know much about plants, your answers are still interesting for us. Thank you.

Location: ________________  
Questionnaire No:  
Name: ________________  

Estimate age category:  
☐ 12-15  
☐ 16-25  
☐ 26-35  
☐ 36-45  
☐ 46-55
Here are photos of four plants found on the Turks and Caicos Islands. 

Hand PHOTOS to respondent

Plant A:

1. Have you seen this plant? Yes □ No □

2. What do you call it? __________________________

3. Have you noticed an increase, decrease or no change in the numbers of this plant in Turks and Caicos over the time you have lived here?

Increase □ Decrease □ No change □

Haven’t noticed a change □

4. Does this plant belong in TCI? Yes □ No □

Don’t know □

5. Does this plant have any positive qualities for you? ______________________________________________________________________

______________________________________________________________________

6. Does this plant have any negative qualities for you?

_____________________________________________________________________

7. Do you use this plant? Yes □ No □
If yes, what for? ______________________________________________________________________

______________________________________________________________________

Repeat for plants B, C and D.

Which island do you live on? (Please tick)

Middle Caicos □
North Caicos □
Providenciales □

How long have you lived in TCI? 
years __ months __

Where were you born? ___________________________

Have you visited the conservation centre on Middle Caicos? Yes □ No □

Thank you very much for your time.
Photos used in social survey (A4 size when printed for survey). Whole trees shown with close up inset.

*Leucaena leucocephala*  
*Pinus caribaea var. bahamensis.*

*Tamarindus indica*  
*Casuarina equisetifolia*
Appendix 2: Results

Figure 1: Number sampled in each habitat

Figure 2: Number sampled in each disturbance type
Table 2: General Linear Model for the impact of habitat type (Habitat), disturbance level (Distid) and invasion/no invasion (U_N) of *C. equisetifolia* on native species richness

<table>
<thead>
<tr>
<th>Model number</th>
<th>Explanatory variables</th>
<th>Interactions</th>
<th>residual deviance</th>
<th>df</th>
<th>chi2 p value</th>
<th>AIC</th>
<th>Notes</th>
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<td></td>
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<td>Distid</td>
<td>U_N</td>
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<td>Habitat: U_N</td>
<td>Dist: U_N</td>
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Figure 3: Locations of sampling points used in Maxent predictive modelling
Table 3: MaxEnt output for all invasive species together

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<tr>
<th>Variable</th>
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<th>Run 3</th>
<th>Run 4</th>
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<td>72.5</td>
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Table 4: MaxEnt output for *Casuarina equisetifolia*

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<td>1.4</td>
<td>2.2</td>
</tr>
<tr>
<td>West</td>
<td>26</td>
<td>25.6</td>
<td>28.9</td>
<td>28.6</td>
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</tr>
<tr>
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<td>0.963</td>
<td>0.93</td>
<td>0.993</td>
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</tr>
<tr>
<td>Training AUC</td>
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<td>0.956</td>
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### Table 5: MaxEnt output for *Leucaena leucocephala*

<table>
<thead>
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<th>Full Model</th>
<th>Run 1</th>
<th>Run 2</th>
<th>Run 3</th>
<th>Run 4</th>
<th>Model used</th>
</tr>
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<td>Roads</td>
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<td>3</td>
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<td>3.6</td>
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<td>1.5486</td>
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<td>0.3584</td>
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<td>0.987</td>
<td>0.966</td>
<td>0.975</td>
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### Table 6: MaxEnt output for *Ricinus communis*

<table>
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<tr>
<th>Variable</th>
<th>Full Model</th>
<th>Run 1</th>
<th>Run 2</th>
<th>Run 3</th>
<th>Run 4</th>
<th>Minus North, South and East</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roads</td>
<td>1.3</td>
<td>6.1</td>
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<td>1.3</td>
<td>1.3</td>
</tr>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>*</td>
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<td>NDVI</td>
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<td>0</td>
<td>1.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>South</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>*</td>
</tr>
<tr>
<td>Band 6</td>
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<td>5</td>
<td>4.3</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
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<td>0.4</td>
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<td>0.98</td>
<td>0.984</td>
<td>0.98</td>
<td>0.98</td>
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### Table 7: MaxEnt output for *Jasminum fluminense*

<table>
<thead>
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<th>Variable</th>
<th>Full Model</th>
<th>Run 1</th>
<th>Run 2</th>
<th>Run 3</th>
<th>Run 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roads</td>
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<td>65.2</td>
<td>15.1</td>
<td>37.3</td>
</tr>
<tr>
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<td>0.3</td>
<td>0</td>
<td>0</td>
</tr>
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<td>2.3</td>
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<td>18.2</td>
<td>31.5</td>
</tr>
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<td>0.5</td>
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<td>9.3</td>
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### Table 8: MaxEnt output for *Scaevola taccada*

<table>
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<th>Variable</th>
<th>Full Model</th>
<th>Run 1</th>
<th>Run 2</th>
<th>Run 3</th>
<th>Run 4</th>
<th>Minus west</th>
<th>Minus North</th>
<th>Minus North and West</th>
</tr>
</thead>
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<td>0</td>
<td>1.3</td>
<td>2.5</td>
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<td>0</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>NDVI</td>
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<td>2.4</td>
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</tr>
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<td>0.2</td>
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<td>0.1</td>
</tr>
<tr>
<td>West</td>
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<td>0</td>
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<tr>
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<tr>
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<td>0.989</td>
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<td>0.992</td>
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</table>
**Figure 4:** Jacknife tests of regularised training gains for all invasive species together

**Figure 5:** Jacknife tests of regularised training gains for *Leucaena leucocephala*

**Figure 6:** Jacknife tests of regularised training gains for *Casuarina equisetifolia*
Figure 7: Jacknife tests of regularised training gains for all invasive species without roads

Figure 7: Jacknife tests of regularised training gains for *Leuceana leucocephala* without roads

Figure 8: Jacknife tests of regularised training gains for *Casuarina equisetifolia* without roads
Appendix 3: Maps

Binary maps showing predicted suitable habitat for five invasive plants and three endemic plants in the Turks and Caicos Islands.
Predicted suitable habitat

- Limonium bahamense, Argythamnia argentea, Encyclia caicensis
- Casuarina equisetifolia, Leucaena leucocephala, Scaevola taccada, Ricinus communis, Jasminum fluminense
- Little Ambergris Cay
Predicted suitable habitat
Limonium bahamense, Argythamnia argentea, Encyclia caicensis
Casuarina equisetifolia, Leucaena leucocephala, Scaevola taccada, Ricinus communis, Jasminum fluminense
All species listed above
South Caicos
Big Ambergris Cay

Predicted suitable habitat
Limonium bahamense, Argythamnia argentea, Encyclia caicensis
Casuarina equisetifolia, Leucaena leucocephala, Scaevola taccada, Ricinus communis, Jasminum fluminense
All species listed above
Big Ambergris Cay
Predicted suitable habitat

- Limonium bahamense, Argythamnia argentea, Encyclia caicensis
- Casuarina equisetifolia, Leucaena leucocephala, Scaevola taccada, Ricinus communis, Jasminum fluminense
- All species listed above

Salt Cay

Predicted suitable habitat

- Limonium bahamense, Argythamnia argentea, Encyclia caicensis
- Casuarina equisetifolia, Leucaena leucocephala, Scaevola taccada, Ricinus communis, Jasminum fluminense
- All species listed above

Grand Turk
Binary maps showing overlap between predicted suitable habitat for the invasive plant *L. Leucocephala* and three endemic plants.
Binary maps showing overlap between predicted suitable habitat for *C. equisetifolia* and three endemic plants.

- **Big Ambergris Cay**
- **South Caicos**

**Predicted suitable habitat**
- Limonium bahamense, Argythamnia argentea, Encyclia caicensis
- *Casuarina equisetifolia*
- Limonium bahamense, Argythamnia argentea, Encyclia caicensis
- *Casuarina equisetifolia*, Limonium bahamense, Argythamnia argentea, Encyclia caicensis
- Big Ambergris Cay
- South Caicos
Predicted suitable habitat

Casuarina equisetifolia, Limonium bahamense, Argythamnia argentea, Encyclia caicensis

Salt Cay

Predicted suitable habitat

Casuarina equisetifolia, Limonium bahamense, Encyclia caicensis, Argythamnia argentea

Grand Turk
Predicted suitable habitat

- Casuarina equisetifolia
- Limonium bahamense, Argythamnia argentea, Encyclia caicensis
- Little Ambergris Cay