Conserving and restoring the Caicos pine forests: The first decade

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ABSTRACT

The severe and rapid attack on the Caicos pine Pinus caribaea var. bahamensis (Pinaceae) by the non-native invasive pine tortoise scale, Toumeyella parvicornis, has resulted in the death of most of the trees in the Turks and Caicos Islands (TCI) in just over a decade. Local and international conservation efforts have enabled the necessary multi-disciplinary research, data gathering, and monitoring to develop and implement a restoration strategy for this endemic tree from the Bahaman archipelago. The native plant nursery established on North Caicos and horticultural expertise acquired throughout the years were crucial to the successful rescue of Caicos pine saplings from the wild populations and cultivation of new saplings grown from locally sourced seeds. These saplings have been used to establish six Restoration Trial Plots on Pine Cay and a seed orchard on North Caicos in TCI. Core Conservation Areas (CCAs) for the Caicos pine forests have been identified and mapped. To date, forest within the Pine Cay CCA has been supplemented by planting more than 450 pine trees, which have survived at a high (>80%) rate.

1. Introduction

The endemic pine Pinus caribaea var. bahamensis (Griseb.) W.H.G.Barrett & Golfari (Pinaceae), known as Caribbean pine in the Bahamas and as Caicos pine in the Turks and Caicos Islands (TCI), is a keystone species and the only native pine tree in the pine forest ecosystem of the Bahaman archipelago (Farjon and Styles, 1997). There are more than 36 major islands and numerous small islands and cays in the archipelago, but pine forests are only present in three of the Turks and Caicos Islands (Middle Caicos, North Caicos and Pine Cay), where they are called pine yards, and four islands in the Commonwealth of the Bahamas (Abaco, Andros, Grand Bahama and New Providence) (Sanchez et al., 2013). The TCI pine population covers only 13 km² of the land, whereas in the Bahamas pine forests cover 2118 km² (Sanchez, 2012).

The pines grow on limestone rock with lateritic soil, usually inland, on larger islands where there are relatively stable water lenses and reduced salt spray (Whitaker and Smart, 1997). The small Pine Cay in TCI, where the main substrate is Holocene marine calcareous sand, is an exception. These are fire-climax pine forests where the pine seeds need light to germinate, benefiting from natural fires which clear areas of broadleaf species present in the undergrowth. It has been observed that in cases where fire is suppressed or absent, species in the undergrowth tend to take over, changing the vegetation from pine forest to coppice over time (Myers et al., 2004). The natural fire interval for the Caicos pine forests in TCI has been estimated at 3–10 years (Hamilton et al., 2016). In pine forests where the main canopy is reduced or lost, as is the case in TCI, researchers have previously suggested the use of prescribed fire to prepare the site, followed by seeding or planting pines to boost natural regeneration (Ross et al., 2009). A plan for prescribed fire management in the TCI pine forests has been suggested by US fire specialists and the Caicos Pine Recovery Project (CPRP) team. This plan is based on local resources and controlled burns carried out in TCI by the team in 2012, 2014 and 2015 (Hamilton et al., 2016; Hamilton and Sanchez, 2014).
The Caicos pines are threatened by non-native invasive pests, fragmentation due to urbanization, and storm surges from hurricanes; consequently, they have been designated as Vulnerable on the IUCN Red List of Threatened Species (Sanchez et al., 2013). Because the Caicos pine is the only native pine across the archipelago, its decline or extirpation will eventually result in the collapse of the pine forest ecosystem.

In TCI, the non-native, invasive insect pine tortoise scale, *Toumeyella parvicornis* (Cockerell) (Hemiptera: Coccidae), has almost driven the Caicos pines to local extinction since its accidental introduction to the country sometime prior to the year 2005 (Malumphy et al., 2012). This pine-specific invasive insect has quickly adapted its biology to TCI. In its native, colder range in northern North America, the pine scale breeds one to four times yearly; in contrast, in TCI, where temperatures are mild throughout the year, the pine scale breeds continuously. This ability to rapidly increase its numbers maximised the potential damage to the Caicos pine populations (Malumphy et al., 2016). As a result, in just over six years since the pest was first recorded, Green (2011) estimated a 97.6% decline in the number of mature pine trees in TCI pine yards (Fig. 1). There are sadly too many similar examples of non-native pests decimating local tree populations around the world, and there is an urgent need for prevention through biosecurity measures, including quarantine of imported plant material and adequate forest pest management (Ayres and Lombardero, 2017).

In 2010, nine Permanent Monitoring Plots were established on three islands (Pine Cay, Middle Caicos, and North Caicos) with pine forests in TCI (Earle-Mundil, 2010). These sites have shown that pine tree health and growth benefited from manual broadleaf removal and applications of soap sprays to reduce infestations (Mark, 2012). However, managing the pine tortoise scale in the wild pine forests at a large scale has not been possible because of a lack of equipment and resources, potential damage to local fauna, and inaccessibility. The lack of financial resources and baseline entomological data for the pine yards has also limited our ability to explore the use of biological controls as an alternative method to control the infestations. Nonetheless, expert entomologist Dr Chris Malumphy from Fera Science Ltd. has joined the team in the field on several occasions to start building the entomological baseline needed for TCI. His findings of several new pest records and some potential pine tortoise scale predators (data unpublished) are important and need further exploration.

The importance of ‘going the extra mile’ to save the Caicos pine forests in TCI is not only because the Caicos pine is TCI’s national tree and a taxon with a restricted range, but that these pine forests form a biodiverse ecosystem at the most eastern edge of the species range. Previous research revealed genetic differentiation at nuclear loci between pine populations of TCI and Bahamas (Sanchez et al., 2014) in addition to some morphological differences in growth patterns (Sanchez, 2012). In turn, this raised the question of how local pines adapt to TCI’s drier and hotter climate and reduced fresh water lenses. Another reason to preserve genetic diversity of the species is to boost species resilience to climate change in the future. Climate change models for the region forecast increased drought and more frequent storm surges (Elsner and Jagger, 2010; IPCC, 2012). Saving as much genetic diversity as possible of these potentially resilient and isolated pine populations can prove crucial for the long-term survival of the species.

In response to the discouraging challenges TCI’s wild Caicos pine populations are facing, the CPRP team of local and international scientists and conservationists have developed a restoration strategy to rescue this taxon from local extinction (Hamilton et al., 2016). The strategy is based on tested horticultural protocols for growing Caicos pines locally (Sanchez et al., 2016b), data from permanent monitoring plots established in the pine yards (Earle-Mundil, 2010) and scientific research on pine population genetics, mycology, restoration ecology, chemical volatiles and seed biology (Green et al., 2017; Sanchez et al., 2016a). Concomitantly, to ensure that sufficient genetic diversity was captured before all mature trees died in the wild, saplings were rescued from badly infested areas, seeds were collected for propagation and gene banking, and saplings were locally propagated for re-introduction.

This manuscript reviews a decade of conservation efforts to save the Caicos pine in TCI, describing the practices developed and used by the CPRP team to restore the Caicos pine forests. It also evaluates and discusses the results obtained so far from established restoration plots and considers the next steps needed for the local survival of the Caicos pine.

### 2. Materials and methods

#### 2.1. Caicos pine ex situ conservation

The *ex situ* collection comprises saplings rescued from the wild and plants grown from local wild source seed in the CPRP native plant nursery, which is located on North Caicos, near Kew settlement, within the North Caicos Government Farm (NCGF). Propagation and cultivation of the Caicos pines from seed follow the CPRP nursery production protocol (Sanchez et al., 2016b), developed mainly through germination and cultivation trials over a four-year period both in-territory and at the Royal Botanic Gardens, Kew (Kew, UK). This protocol recommends first the removal of the seed wings, followed by disinfection of the seeds in 3% hydrogen peroxide for 2–3 min with a final rinse in cold water, and finally a 24–48 h water-soaking treatment pre-sowing. Any floating seeds are separated at the end of this period and discarded (if seeds are very scarce these can be sown separately to capture any eventual germination). Seeds that float, according to our trials and experience, are usually empty and/or tend not to germinate (Sanchez et al., 2016b). Sunken seeds are sown in TH-1 All-Purpose Professional Growing Mix (Theriault & Hachey Peat Moss Ltd.) with a fine layer of sterilised sand on top (Fig. 5). Doubling the number of seeds for the final expected number of plants is recommended, because germination rates observed were low (22.6%–52.5%). Seedlings are pricked out 3–5 weeks later into a mix of TH-1 All-Purpose Professional Growing Mix (widely available locally) and local soil (collected either from the pine yards or from NCGF in areas that have not been farmed yet or have been fallow for over 30 years) (Fig. 5). This ensures the presence of essential mycorrhizal fungi for pine establishment. All seedlings are assigned a unique ID number.

![Fig. 1. Caicos pine forest on Middle Caicos, TCI. Old dead pines killed by the pine tortoise scale prevail, but small areas with new, natural regeneration near mature surviving trees bring hope for the future.](image)
A Caicos pine seed orchard was also established in 2013 at the NCGF. The area, which used to be rock-ploughed for vegetable production in the past, had to be manually cleared of the invasive non-native tree *Leucaena leucocephala* (Lam.) de Wit. before planting out a total of 146 pine trees and saplings. These pines were exclusively from North Caicos and Middle Caicos provenances, as these two populations are genetically similar (Sanchez et al., 2014). In the context of this research and project, we categorised pine trees according to height and diameter at breast height (dbh defined as 130 cm above ground level) (Sanchez, 2012) as follows:

- seedlings < 30 cm height;
- saplings > 30 cm height and under 3 cm dbh;
- and trees > 3 cm dbh (Sanchez et al., 2016b).

In December 2015, saplings and trees in the nursery (122) and seed orchard (130) were genotyped using the same five nuclear microsatellite markers applied in the past to evaluate the genetic diversity of the wild population. The resulting list of genotypes was made available to the CPRP team (Sanchez et al., 2016a).

Seeds from the wild Caicos pine populations are collected annually from August to October following the CPRP Seed Collection Protocol (Sanchez et al., 2016b), keeping collections from different islands (provenance) separate. Seeds that are not used for propagation are sent to Kew’s Millennium Seed Bank (MSB) in the UK for long-term storage at 15% RH and –20 °C, as tests indicated that seeds from this taxon are orthodox (Sanchez et al., 2016b). A total of 12 seed collections of Caicos pines from TCI have been banked at the MSB from 2011 to 2015. The total number of good seeds (6408) is an adjusted figure estimated following quality assessment tests. Half of the collections are from Middle Caicos provenance (3776 seeds; MSB serial numbers 650830, 818078, 818056, 870056, 870067, 870089) and half are from Pine Cay provenance (2632 seeds; MSB serial numbers 650829, 818090, 818089, 818067, 870078, 870090).

2.2. Restoration trial plots

The Diamond Jubilee pine yard on Pine Cay, named after HM Queen Elizabeth II’s Diamond Jubilee, was chosen to establish the initial restoration plots. The choice was based on it being one of two remaining Crown Land parcels on that island, with ease of access, presence of some mature and young pine trees and ideal planting conditions due to the sandy substrate and lack of exposed limestone. The area also has slightly ‘higher’ topography (c. 2–3 m above sea level) in this low-lying cay with two ridges of lithified dunes running through the parcel.

Six trial plots were established to determine the best methodology and aftercare requirements for successful establishment of nursery grown plants. Intentionally laying out some of the plots in slightly higher terrain was part of an experimental assisted migration for the Caicos pine to increase its resilience to sea level rise. The methodology used for the establishment of the trial plots and initial data collection is described by Hudson (2012). It consisted of laying out 20 m × 20 m (400 m²) plots with North to South orientation, each with 25 quadrats of 4 m × 4 m. A 2-m-wide walkway was created around the six plots and between groups of three plots to ensure ease of access, reduced soil compaction and serve as a fire break. Each plot was planted with 25 pine trees from Pine Cay provenance, observing a minimum distance of 2 m apart between trees to reduce competition for nutrients and light and maximize growth (Figs. 2 and 3). The planting density was based on the most common naturally occurring pine tree density of Pine Cay’s pine forests of up to 5 mature trees per 100 m² (Sanchez, 2012).

Plots 1, 2 and 3 were planted in May 2012 (Hudson, 2012), with two more plots, 4 and 5, planted in January 2013 and a final plot, 6, planted in May 2014. Saplings were planted at the start or during the wet season (May to August), watered immediately after planting and every 10–20 days after that for the first month if there was no rain. Only Pine Cay provenance saplings were planted on
Pine Cay, following recommendations of previous research which showed genetic differentiation of this population (Sanchez et al., 2014). All pines in the trial plots had unique ID number tags attached to them (large saplings and trees) or affixed to an aluminium stake adjacent to the root ball (small saplings and wild seedlings). The number tags were either assigned to each plant during pricking out in the nursery (cultivated material) or when laying out or monitoring the plots (existing wild pines).

Broadleaf vegetation was manually removed around new seedlings and established pines within the plots before data collection. All pines were plotted (Fig. 3) using a Trimble Juno Series S handheld computer with built-in GPS and MS Windows Embedded Handheld 6 OS running ArcPad™ v.10 software (©1995–2015 ESRI) using a preloaded grid layer to enable manual plotting due to GPS accuracy of ±10 m.

Restoration Trial Plots 1, 2 and 3 were monitored annually between November and January (natural period for pine recruitment after the rainy season) in 2014 and 2015 (Fig. 2). Existing data were loaded onto the handheld computers prior to monitoring. New data were captured in customised ArcPad recording forms including observations within the plots of live/dead pines, measurements of height and dbh of wild and cultivated pines, estimation of pine tortoise scale infestation level (ordinal scale 0–5) and descriptive notes. Data were then exported to a database created using Brahms v.6.04 (©1985–2010b, Department of Plant Sciences, University of Oxford), where it could be ‘cleaned’, manipulated and exported to other software and shared with the project team.

Restoration Trial Plots 1, 2 and 3 were monitored annually following the same methodology as part of the CPRP National Tree Restoration Strategy (Hamilton et al., 2016).

2.3. Core conservation areas

Core Conservation Areas (CCAs) for each pine forest on Middle Caicos, North Caicos and Pine Cay were identified by the project team in a workshop setting during the development of the restoration strategy for the Caicos pine forests using the GIS created and developed by the project team for TCI (Hamilton et al., 2016; Sanchez et al., 2016b). Three criteria were considered when identifying CCAs: a) public or privately-owned land that is not earmarked for development; b) land shows visible signs of potential resilience to sea-level rise (higher elevation or areas less likely to flood); and c) presence of living mature trees (regeneration potential). The North Caicos CCA is considerably larger than the remaining pine forest due to the large area of Crown Land on the island that previously supported pine forests. Table 1 shows the size and details for each CCA, while Fig. 4 shows the location of the individual CCAs in the islands.

2.3.1. Pine Cay CCA pine forest restoration

In 2015, 2016 and 2017 the management of the CCA on Pine Cay expanded beyond the restoration trial plots with the planting of the entire western parcel of Crown Land. The raised area adjacent to the trial plots was demarcated and manually cleared of broadleaf vegetation prior to planting. All saplings were obligatorily from Pine Cay seed provenance and grown by the Department of Environment and Coastal Resources (DECR) authors at the CPRP native.
plant nursery on the NCGF with expert horticultural guidance from Kew staff and volunteers, following the guidelines described previously (see 2.1). Saplings were selected 6–8 weeks before planting-out at restoration sites if the following criteria were met: plants large enough to be grown in 3-gallon pots or larger; apical branch of the sapling not broken or damaged; root ball even and filling the pot without spiralling around the bottom; and growth not distorted or abnormal. After selection, saplings were hardened off by reducing watering gradually and exposing them to partial shade and then full sun. They were also checked for pests regularly and treated if necessary. Planting-out and aftercare followed the same procedures described in 2.2 and the CPRP restoration protocol (Sanchez et al., 2016b).

2.3.2. Middle Caicos CCA pine forest restoration

In 2009, regional experts in prescribed fire use and pine forest management were invited to TCI by the local government to assist the newly established CPRP team with gathering baseline data on forest structure and health, and assessing whether the forests, available resources, and infrastructure at TCI were suitable for prescribed fire use. The overwhelming response was to focus management efforts on the Middle Caicos pine forest, where a higher number of mature trees remain, a large part of the forest is on Crown Land and accessible by road (Fig. 4), and there are areas at relatively higher elevation. Following these recommendations, the CPRP team established access trails (~1 m wide) and fire breaks (~2 m wide) and demarcated prescribed fire plots to enable prescribed fire training to be undertaken within the Middle Caicos CCA in 2012, 2014 and 2015. The Middle Caicos CCA also contains three of the Permanent Monitoring Plots established in 2010 (Earle-Mundil, 2010).

Table 1

| Island        | Land area | Pine forest area | CCA | Ownership | Features                                                                 |
|---------------|-----------|------------------|-----|-----------|--------------------------------------------------------------------------|
| Middle Caicos | 277.9 km² | 11.5 km²         | 3.25 km² | Crown land | Permanent monitoring Plots, Prescribed Fire Plots and Caicos Pine Yard Trail |
| North Caicos  | 206.1 km² | 0.4 km²          | 10 km²  | Crown land | Permanent Monitoring Plots                                               |
| Pine Cay      | 3.7 km²   | 1.1 km²          | 0.2 km² | Crown and private land | Diamond Jubilee Pine Yard, Restoration Trial Plots                        |
| Total         | 487.7 km² | 13 km²           | 13.45 km² | N/A       | N/A                                                                      |

Fig. 4. Map of pine forests and Core Conservation Areas (CCAs) in the Turks and Caicos Islands. Larger map shows pine forests (green), burnt area without regeneration after accidental non-seasonal wildfire in 2009 on North Caicos (hashed-orange) and demarcation for individual CCAs on each island. Inserts on the right show an overview of the islands’ location within the territory and region.

2.3.3. North Caicos CCA pine forest restoration

Following an escaped agricultural fire in 2009 that destroyed much of the North Caicos pine forest and killed all trees accessible by existing roads (Fig. 4), the CPRP team developed a trail (~1 m wide) partially based on a historic path (Manco et al., 2016) to access patches of the remaining forest. This enabled the development of three Permanent Monitoring Plots in 2010 (Earle-Mundil, 2010) within the North Caicos CCA, seed collecting from the few trees that survived the fire, seedling rescue from areas prone to flooding, and comparative research across the three CCAs as reported in Green et al. (2017) and Sanchez et al. (2016a).
3. Results and discussion

3.1. Conservation ex situ

Local nursery production of new saplings is a priority for restoration work in TCI. In the last decade, the Kew authors of this manuscript and Kew volunteers were able to share their horticultural expertise and work together with the DECR authors to develop and test techniques for the propagation and cultivation of Caicos pines using locally available resources and facilities, resulting in the CPRP nursery production protocol (see 2.1). The DECR authors are now able to produce an average of 160 pines/year in the CPRP native plant nursery and since it was established more than 500 pines have been grown there (Fig. 5). Research by Kew mycologists has confirmed that the addition of local soil into the nursery growing media, started by the DECR authors, ensures that the necessary mycorrhizal fungi are present during pine development and at time of planting, maximising chances of survival (Sanchez et al., 2016a). Also, the problem of damping off in small seedlings has been greatly reduced since the introduction of new methods; namely sterilizing seeds, covering seed tray media with sterilized sand, placing seed trays under a covered area and watering seed trays from below (immersion method).

Caicos pine trees planted-out in the seed orchard (146) had a high rate of survival (c. 84%) with only 23 deaths recorded. Similar survival rates have been reported on degraded sites in the USA using nursery grown *Pinus taeda* L. plants (Bell et al., 2017). Various factors contributed to tree deaths in the seed orchard, including tree bark damage caused by escaped goats from the NCGF enclosure, wind damage from the 2017 hurricanes, and failure to establish for unknown reasons. Specific trees have had sporadic infestation with the pine tortoise scale, but localised applications of soap spray, neem oil and systemic insecticides (e.g. Lannate® and Malathion®) supplemented by manual control methods (e.g. wiping needles with alcohol-moistened cloth before rinsing with water) have thus far managed to control the pest outbreaks in the nursery and seed orchard. In 2015, pine trees in the seed orchard had their first mature cones and in the two subsequent years small seed collections were possible. As trees grow larger, we hope that seed production will increase. This is particularly important as there are several trees of North Caicos provenance in the NCGF seed orchard. The wild pine tree population on North Caicos was almost wiped out by the accidental escape of an agricultural fire in 2009 which destroyed 91.5% of the forest (Sanchez, 2012), as shown in Fig. 4, and currently very few mature wild trees are left in the North Caicos pine forest. Also, the remaining wild trees have not been producing cones in recent years due to the pest infestation. Genetic research on the seed orchard trees revealed that this collection holds most of the genetic diversity of the wild populations, as well as some alleles that have not been detected in the wild previously (Sanchez et al., 2016a). Therefore, the trees in the seed orchard are very important for the conservation of the genetic diversity of the taxon and restoration efforts.

In September 2017, hurricanes Irma and Maria destroyed the nursery structure, but pro-active preparations by the nursery manager prior to the hurricane meant that only one pine tree was lost. This experience and effective action taken can be applied to mitigation measures by writing a formal disaster preparedness plan for the nursery, currently non-existent, which could then be implemented in the face of an on-coming storm. During the 2017 hurricanes, 38 of the trees in the seed orchard were blown over. After the event, these trees were uprighted and staked. Despite severe root disturbance and an increase in scale insect infestation, trees are still alive and the DECR authors think that most have a good chance of recovery once the infestation is controlled.

Climatic changes and natural disasters reaffirm the importance of long-term seed banking whenever possible for the Caicos pine. A
collection of genetically diverse seeds with good viability can always be used to re-start plant production and restore damaged forest areas.

3.2. Conservation in situ

The high rate of survival for cultivated pines (80%) in the Restoration Trial Plots 1, 2 and 3 on Pine Cay over a three-year period (2012–2015) confirmed the success of the plant selection, preparation, and out-planting methods used. Out of the 75 pines planted in 2012, nine were recorded dead in 2014 and six in 2015, mainly due to infestation by the pine tortoise scale, because pest control was not possible in wild locations. This survival rate was like the one reported for *P. taeda* trial plots (85%) in degraded areas in Kentucky, USA, during restoration using similar plot sizes (Bell et al., 2017).

The survival rate for the wild pines (including seedlings, saplings, and trees) in the same Restoration Trial Plots 1, 2 and 3 was 82.2%, with death of seven pines by 2014 and another 9 pines in 2015, predominantly due to pest infestation. However, it is important to note that natural regeneration did happen during this period. Wild seedlings recorded for plots 1, 2 and 3 in 2014 (8 live individuals) and 2015 (54 live and 6 dead individuals) were mainly underneath and adjacent to a large mature tree on the boundary between plots 1 and 2 (Fig. 2). This shows that natural regeneration can complement restoration efforts when there are mature trees with cone production in and adjacent to the plots where broadleaf vegetation clearance is undertaken. Despite these events of natural regeneration, death of wild seedlings and saplings due to pest infestation and localised flooding is still an issue.

In plots 4, 5 and 6, the overall survival rate for cultivated pines in 2015 was 90%, indicating that the methods trialled and applied to restoring areas have been effective. These results confirm that the choice of planting-out saplings in 3-gallon pots or larger seems to be working as these larger plants are more resilient to weather conditions and pests than smaller seedlings. Minimizing water stress in the newly planted pines by choosing the right planting time (start of wet season) and following aftercare guidelines contributed to survival success and pine establishment in the restoration areas.

Following the success of the restoration trial plots, more extensive restoration efforts were applied to the CCA on Pine Cay in 2015 by planting 146 Caicos pine saplings in the raised area adjacent to the trial plots (Hamilton et al., 2016). The focus was to plant saplings higher onto the dune ridges than they normally grow, as a form of assisted migration to help reduce the effects of predicted sea-level rise on the local pine forest. This was followed by further planting of 157 saplings in August 2017 by the DECR authors with assistance from the Meridian Club and TCI Department of Agriculture staff. Survival rates have been very high with only a few trees failing to establish or dying back due to pine tortoise scale infestation. The extensive trials and development of the CPRP nursery production protocol and CPRP restoration protocol (Sanchez et al., 2016b) were key to ensuring that mortality after planting decreased and establishment success increased.

In September 2017, several of the newly planted saplings were topped by strong winds during Hurricane Irma, but after being uprighted the DECR authors feel the trees will continue growing. Time will tell if these pines manage to re-establish or not, but so far, they have shown great resilience to extreme environmental conditions.

The initial restoration work has generated data that can be used to assess successes and develop a long-term restoration strategy for the taxon. The identification of the three CCAs has enabled the team to focus limited resources and available time to priority areas. Currently, none of the pine forests in TCI are inside protected areas, and even after mapping was carried out by Kew’s GIS team in 2008 (Hamilton et al., 2010) many areas remain quite inaccessible.

Pine Cay is the smallest island with pine forests, but as the name implies, these occupy almost a third of the island (Table 1). The local homeowner’s association and the Meridian Club have been very supportive of the project throughout. They have provided transport of nursery-grown Caicos pines via private boat from North Caicos, facilitated access for surveys and seed collecting, and provided local transport of people and supplies to enable the installation of monitoring and restoration plots and interpretation panels. The CCA on this island is located inland and contains the permanent monitoring plots and the restoration plots (Fig. 4). As genetic work has highlighted (Sanchez et al., 2014) this population is important for the future conservation of TCI’s Caicos pine due to genetic differences and adaptation to unique conditions, e.g., sandy soils in exposed locations. The initial success of restoration on this island by the CPRP along with large quantities of seed available for nursery production of saplings, local support, and ease of access for out-planting have been the main drivers for the concentration of restoration efforts thus far on this island.

The restoration strategy for the Caicos pine forests (Hamilton et al., 2016) also recommended concentrating efforts on Middle Caicos, suggesting a 10-year planting schedule with a three-phase planting, where 25 trees are planted in year 1 and another 25 trees planted in year 6 in the same plot. This scheme, which would start with four plots and interplant them over a 5-year interval, would result in a mosaic of trees of different ages, making the stands less susceptible to damage and uprooting during strong winds (Gardiner et al., 2005). Because climate change models predict more intense hurricanes for the Caribbean region in the future (Elsner and Jagger, 2010), the elements of this scheme that reinforce pine forest resilience to strong winds are essential. This can also be applied to other islands or scaled up if necessary.

The CCA on Middle Caicos does not include all of the pine forests found on the island (Fig. 4); however, it does focus on the area where three prescribed fires were carried out by the CPRP team under the leadership and supervision of fire specialists from the USA in 2012 and 2014 (Hamilton and Sanchez, 2015, 2014). Fire breaks have been established around the CCA and are maintained annually. Prescribed fires have been identified as essential in TCI to maintain the ecological health of pine yards and reduce fuel loads to prevent damaging wildfires. This CCA is also important for containing the permanent monitoring plots and the Caicos Pine Yard Trail (Table 1). The latter is a self-led interpretive trail launched at the end of 2015, which was created by the CPRP in the pine forest ecosystem to raise awareness of TCI’s National Tree, the Caicos pine, the biodiversity of the area, and the conservation challenges this ecosystem faces. The trail has been popular with local schools, tourists, and the local community since opening, while contributing to the local green economy.

The conservation of North Caicos pine forests is also of importance, and a CCA has been identified and mapped on this island (Table 1, Fig. 4). However, access to the area is very difficult and requires a hike of almost an hour through cut trails, which can make carrying plants, water, and equipment for out-planting very challenging. Thus, difficulty of access coupled with lack of natural regeneration and limited seed source have set back North Caicos on the list of priority sites for restoration.

Another resource produced for the CPRP via the restoration strategy was an annual activity implementation table (Appendix, Table A.1) which considers local conditions and resources throughout the year. This table was thoroughly discussed and agreed on among CPRP team members and aims to provide an outline of which activities need to be prioritised to allow continued restoration efforts to succeed.
4. Conclusions

The long-term collaboration between Kew and DECR has enabled local and international expertise to be applied to building capacity in-country and developing a restoration strategy for the Caicos pine in TCI. Local project members were able to develop the skills necessary to carry on the restoration programme, i.e. propagate, cultivate, plant, and care for the Caicos pines in situ and ex situ, in addition to having in place the essential equipment and infrastructure to do so. Unfortunately, hurricanes Irma and Maria in 2017 destroyed the physical nursery structure and currently new funding sources are being sought for rebuilding. Thanks to the CPRP community outreach campaign in the past years, the local community and TCI government have been supportive of the restoration programme for TCI’s National Park, the Caicos pine.

The restoration trial plots and seed orchard were extremely useful for testing the establishment success of nursery-grown pines in different ecological situations. They showed that the methods used were effective, resulting in high survival rates for cultivated pines. The restoration trial plots and prescribed fire plots also showed the importance of existing mature fertile trees in the wild in contributing to the natural regeneration of the pine forests when broadleaf competition is removed (e.g. through prescribed fire, mechanical or manual removal).

The propagation and cultivation protocols developed were being used to produce adequate numbers and quality nursery-grown Caicos pines for restoration efforts on Pine Cay; however, if restoration is to be undertaken on other islands, it would be necessary to scale up nursery production and recruit extra staff. These activities would require additional funds. The Middle Caicos CCA is the next priority area for restoration due to the presence of patches of healthy trees and some natural regeneration. Initial site preparation via prescribed fires and the installation of fire breaks have been undertaken and the location near Conch Bar Caves National Park and the self-guided Caicos Pine Yard Trail makes this area an ideal candidate to target for future Caicos pine forest restoration efforts in TCI.

As long as the pine tortoise scale infestation continues and its effects on the Caicos pine forests are detrimental, human intervention is necessary. Specifically, conservationists are needed to aid the pine population’s survival and resilience, as well as to limit declines in genetic diversity. Seed collection, propagation and restoration efforts should all continue. The continued support of TCI government and stable funding of the restoration programme are just as important as the CPRP team’s dedication and skill set. Building on the foundations laid over the previous decade will not be easy, but the blueprints are available to construct the restoration program needed to secure the future of the Caicos pine. Long-term monitoring of these restoration plots can provide the dataset to help determine the management of the pine forests and ultimately ensure the survival of this vulnerable, endemic tree.

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Appendix A. Annual activity implementation table

Table A
Annual Activity Implementation Table for the Caicos Pine Restoration Strategy, PMPs- Permanent Monitoring Plots; MC CCA- Middle Caicos Core Conservation Area; NC CCA- North Caicos Core Conservation Area

| Strategy theme                  | Theme activities       | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|--------------------------------|------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Seed collection                | Pre-harvest monitoring | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   |
|                               | Seed harvesting        | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   |
|                               | Post-harvest seed processing | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   |
| Nursery production             | Seed sowing            | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   |
|                               | Re-potting             | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   |
| Seed orchard management and expansion | Weed management         | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   |
|                               | New area preparation   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   |
|                               | Sapling selection and quarantine | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   |
| Habitat management             | PMPs broadleaf clearance | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   |
|                               | MC CCA fire breaks/trails clearance | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   |
| Out-planting                   | Site selection and preparation | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   |
| Monitoring                     | Permanent Monitoring Plots | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   |
|                               | Pine Cay restoration plots | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   |
|                               | Middle Caicos restoration plots | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   |
|                               | Seed orchard           | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   |
|                               | CPRP nursery           | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   | ✓   |
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