Adaptive Management: Pond Apple Control In the Catchments of the Russell-Mulgrave and Tully-Murray River Systems

WET TROPICS MANAGEMENT AUTHORITY

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Environmental Protection Agency
Queensland Parks and Wildlife Service

Adaptive Management: Pond Apple Control in the Catchments of the Russell-Mulgrave and Tully-Murray River Systems

A report to the Commonwealth Department of Environment and Heritage

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Cover image by Ian Holloway: An even-aged stand of pond apple trees at Eubenangee Swamp National Park.

All images by Ian Holloway.

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Background

Pond apple (*Annona glabra*) is a major environmental weed of the Wet Tropics bioregion of North Queensland and is designated as a Weed of National Significance (WONS). This small tree forms dense stands particularly in swamp communities to the exclusion of native species. Pond apple prefers the silty alluvial soils of coastal flood plains. Pond apple seed is viable for up to two years. Its primary method of dispersal is by water, particularly flood events. Long distance dispersal by animals is considered to be insignificant compared to its rapid and wide-spread dispersal by floodwaters. Disturbed flood prone ecosystems are the most at risk from pond apple invasion and it represents a very significant threat to many lowland riparian vegetation communities in the Wet Tropics.

Project Aims

In 2001 funding was acquired by the Wet Tropics Management Authority from the Natural Heritage Trust through the WONS program. The aims of the project were to:

1. Identify and map the known infestations of pond apple within the Cape Tribulation to Cardwell section of the Wet Tropics bioregion and predict areas most at risk from further invasion.
2. Identify areas of high priority for control, using critical habitats most at risk from pond apple invasion as the key criterion.
3. Conduct an adaptive management trials program within the Wet Tropics bioregion, specifically the Tully-Murray and Russell-Mulgrave catchments.
4. Undertake a community awareness and education program, including the production of a best practice booklet on various pond apple control techniques for a variety of situations and habitats.

Focussing on adaptive management techniques for pond apple control, this project was one component of a six-part funding proposal addressing high priority actions identified in the WONS Pond Apple Strategic Plan (2001).

Mapping pond apple distribution

Mapping was separated into a two-stage process. The first stage involved mapping the current distribution of pond apple in the Wet Tropics bioregion while the second stage was the predictive modelling of areas considered most at risk from new invasions.

The accurate plotting of the current distribution of pond apple was achieved through a program of field surveys with the aid of Geographical Positioning System equipment. Approximately 2,000 hectares of pond apple affected vegetation were identified. This data was correlated with vegetation types to predict which types were most at risk from invasion. These broad ‘at risk’ vegetation types were then subdivided to focus on disturbed native vegetation below 20 metres altitude as this represents those areas most at risk from seed dispersal by floodwaters. Approximately 43,000 hectares were identified as being at potential risk from pond apple invasion.

Control Programs

Based on a catchment planning approach, two rounds of control trials were undertaken at a number of sites. It should be noted that there was insufficient time for follow-up work within any of the treated areas. The most effective control techniques trialled were cut stump for smaller trees, stem injection for larger trees and the felling of trees over 25 centimetres diameter with immediate herbicide treatment of stumps. It is recommended that treated trees should be left *in situ* to reduce further disturbance to an area. Follow-up work will be crucial to the long-term success of this project and should be an essential component of any future control programs.

Based on work done in 2003, the average cost to undertake initial control of a pond apple infestation was $2,860 per hectare. Costs varied for different types of infestations and control technique used. The initial cost to eradicate pond apple from the whole of the Wet Tropics bioregion is estimated to be in the vicinity of $3,850,000. This estimate does not include follow-up costs that would be essential for at least a further two years.

Community awareness and education

Liaison and information sharing was an integral part of the project and was particularly effective with regional Queensland Parks and Wildlife Service (QPWS) field staff and staff from the Douglas, Johnstone and Cardwell Shires and Cairns City Council. Awareness of the project was promoted through the media and community field days.

Recommendations

Key recommendations include the need for:

- *Additional predictive mapping* following the completion of the 'Vegetation Mapping of Wet Tropics Bioregion' (Stanton & Stanton (completion date mid-2005)), using criteria developed in this project.
- *Further field surveys* to verify the accuracy of predictive mapping.
- *Further control* with priority given to areas where eradication is achievable. In selecting areas, consideration should be given to the size of the infestation, external seed sources and the availability of resources for follow-up control.
- *Further research* on pond apple ecology and distribution including:
  - the relationship between disturbance of natural vegetation and pond apple invasion;
  - relationships between seed dispersal and specific flood/cyclonic events; and
  - relationships between seed dispersal and a variety of animal species in isolated outbreaks of pond apple.
- *Ongoing community education* on the identification, reporting and control of pond apple, including how to access the latest information on the control of pond apple from the Department of Environment and Heritage, and other relevant websites.

1. Introduction

1.1 Project scope

Funding for this project was acquired by the Wet Tropics Management Authority from the Natural Heritage Trust through the Weeds of National Significance (WONS) program.

This project was originally designated as 'component 4B' of an integrated six part proposal (**Table 1)** designed to address several high priority actions identified in the WONS Pond Apple Strategic Plan (2001).

Table 1: Integrated proposal for pond apple control, consistent with priority actions identified in the WONS Pond Apple Strategic Plan (2001)

Component 1: Development of an education and awareness program and a pond apple best practice manual. Total Budget - $198,300; NWP Requested $87,500
Component 2A - Determining pond apple seed spread, seed viability and potential dispersal of pond apple by water. Total Budget - $74,600; NWP Requested $36,000
Component 2B - Determining pond apple seed spread: by animal vectors. Total Budget - $46,600; NWP Requested $16,200
Component 3A – Strategic on ground control: Pond Apple eradication in the Mareeba Shire. Total Budget - $183,300; NWP Requested $82,500
Component 3B – Strategic on ground control in the Daintree River and Bailey Creek Catchments. Total Budget - $110,400; NWP Requested $54,500
Component 3C – Strategic on ground control in the Lower Johnstone Catchment. $234,000; NWP Requested $116,900
Component 4A – Adaptive Management: Developing and demonstrating best practice methods for control and rehabilitation of Pond Apple infestations. Total Budget - $656,600; NWP Requested $323,100
Component 4B – Adaptive Management: Pond Apple control in the catchments of the Russell–Mulgrave and Tully–Murray River Systems. Total Budget - $426,900; NWP Requested $213,700
Component 5 – Devolved grant for community-based on ground control: Accelerated Community Based NRM Outcomes in the Wet Tropics region. Total Budget - $678,900; NWP Requested $338,000
Component 6 – Mapping current infestations: Developing remote sensing procedures for early detection of new Pond Apple infestations. Total Budget - $16,400; NWP Requested $7,800

Component 4B was designed to complement the other components of the overall project by:

- developing various management procedures and utilising them as case studies for a best practice manual (component 1);
- hosting a field day at one of the sites treated in this project to educate the community on the importance of pond apple management (component 1);
- developing and refining control tools that can be incorporated into strategic on-ground control projects (component 3); and
- utilising and developing remote sensing technologies for the detection of current infestations (component 6).

As only three components were funded (Components 3A, 3B and 4B), the aims for the project were modified to:

- map the known distribution of pond apple, across all tenures within the Wet Tropics bioregion from Cape Tribulation to Cardwell (see **Map 1**);
- correlate current patterns of pond apple distribution with native vegetation types[1] invaded to develop a predictive model to aid in the identification of areas at risk of pond apple invasion using Geographic Informatin System (GIS) (ARCVIEW);
- identify and document the most effective methods of control;
- identify high priority areas based on the conservation status of susceptible regional ecosystems;
- conduct adaptive management trials within the bioregion, concentrating on the Tully-Murray and Russell-Mulgrave catchments; and
- undertake a community awareness and education program including the production of a best practice booklet on various pond apple control techniques considered most effective in different situations and habitats.

To deliver the outcomes of the project a coordinator was funded and assigned to the Queensland Parks and Wildlife Service (QPWS).

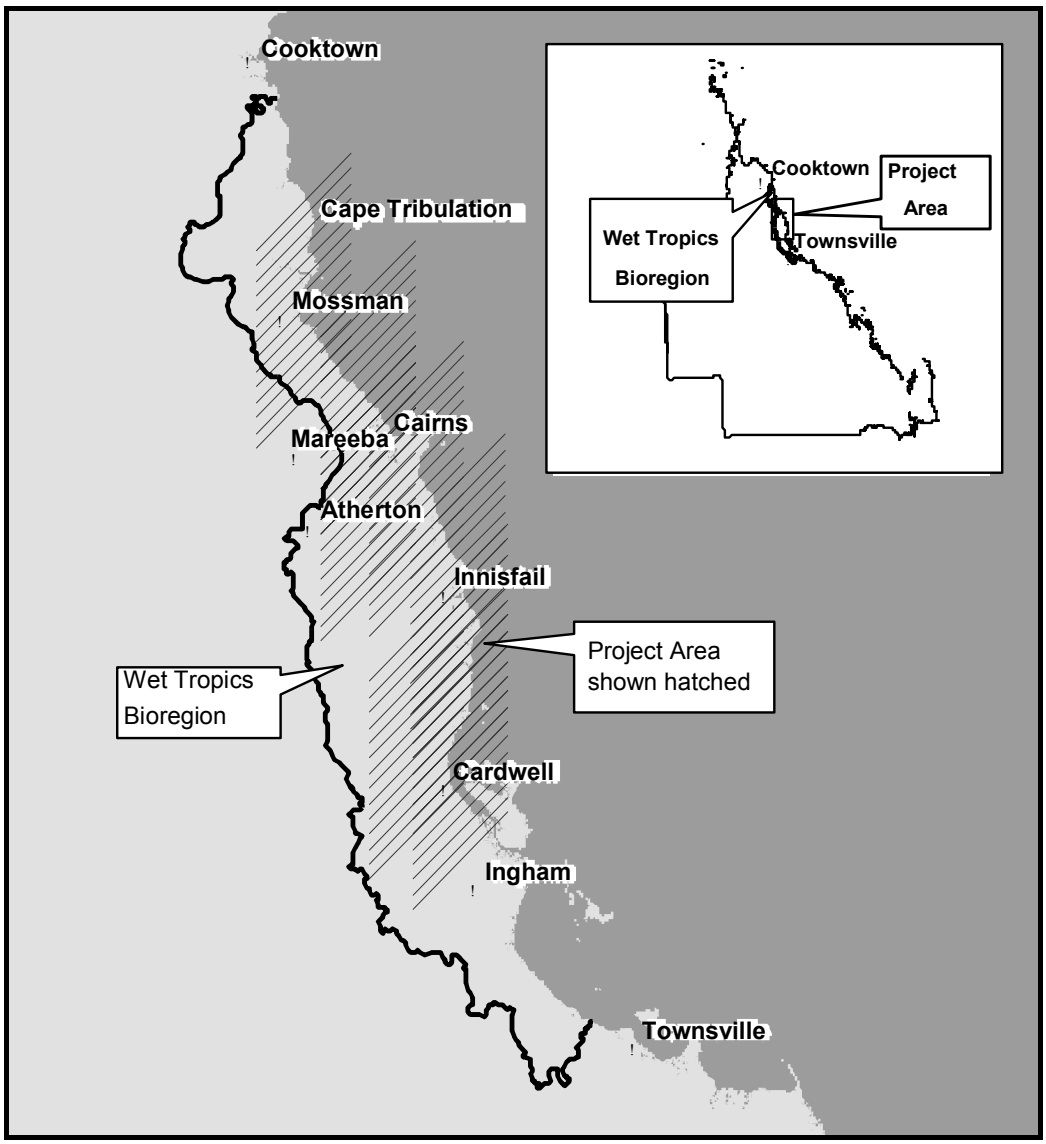
The project commenced in July 2002 and concluded in October 2003.

1.2 Project study area

The project study area was located between Cape Tribulation and Cardwell within the Wet Tropics of Queensland bioregion (refer **Map 1**).

[1] Using Vegetation Mapping of the Wet Tropics bioregion (Stanton & Stanton in prep.)

Map 1: Project study area



The area was divided into 35 management subunits based on river catchments. **Map 2**, located at the end of the report, shows the location of these subunits and should be consulted for river and creek locations referred to in this report.

Initial trials focused on the Russell-Mulgrave and Tully-Murray River catchments, however, the Johnstone and Daintree River systems were subsequently included following the mapping component of the study.

1.3 Pond apple description

Pond apple (*Annona glabra*) is a native of the Central Americas (Florida, Mexico, Honduras, Nicaragua, Costa Rica, Ecuador, Columbia, Puerto Rico and the West Indies) and appears to have spread naturally to coastal West Africa (WONS Pond Apple Strategic Plan 2001) and has recently become established in South East Asia. *Annona glabra* has several common names including: pond apple, alligator apple, bullock's heart, and cherimoya[2] (PIER 2003).

[2] Cherimoya is the North American name for the commercial custard apple, *Annona cherimola*, which is closely related to pond apple

Pond apple is a semi-deciduous tree usually growing to six metres in height but may reach 15 metres under ideal conditions. When young, pond apple often has multiple stems whereas mature trees normally have a single, narrowly buttressed trunk. Stems are covered in a grey bark, and as is common of many plants that grow in water-logged environments, the bark is dotted with lenticels (small raised pores which assist in gas exchange). Leaves are between 7cm and 12cm long, with pale green undersides and a distinctive small fold at the base near the stalk. Many of the dull green leaves of mature trees turn yellow or orange in the period June to September or, in drier areas, through to October, a distinctive feature which assists in their aerial detection (see **Image 1**).

Reproductive maturity is attained after two years. Flowers are small (20-30 mm diameter), pale yellow or cream coloured, with a bright red base. Fruit form over the summer and autumn months before dropping from the tree and ripening. During ripening the skin of the fruit turns from green to yellow to black while the flesh becomes orange. The fruits contain around 140 pumpkin-like seeds (Setter 2002). Germination peaks following rainfall and a period of temperatures above 25^{o}C. Both fruit and seed float which facilitates efficient dispersal in flowing water.

The first record of pond apple in Australia was in 1886 at the Cooktown Botanic Gardens. It was not until 1912 that it was introduced into cultivation as grafting rootstock for commercial custard apple production.

2. Pond apple ecology in the Wet Tropics bioregion

Like all plants, pond apple has particular habitat preferences. These preferences define its ability to spread, establish and invade new areas.

2.1 Soil preferences

From its current pattern of distribution within the Wet Tropics it can be inferred that pond apple prefers the silty alluvial soils of the coastal flood plains characterised by high water retention properties. It is less likely to be found in sandy soils, or in sandy river systems. In sandy river systems pond apple is usually confined to areas of silt accumulation such as in channels and overflows. Examples of these in the Wet Tropics are Liverpool Creek and the Mulgrave River.

2.2 Rainfall and temperature regimes

Pond apple has a broad climatic tolerance, with the main limiting factor being its requirement for high levels of soil moisture. Although its pattern of distribution in the Wet Tropics suggests pond apple has a preference for high rainfall (over 1500mm per year), this level of annual precipitation is not essential as long as soil moisture levels remains high. For example, the infestation at Paddy's Creek near Mareeba occurred in an area with an average annual rainfall of only 750mm (WONS Pond Apple Strategic Plan 2001).

While temperature does not seem to be a critical factor in pond apple survival, it does require temperatures of above 25^0C for seed germination (Baker, Dorney and Hammer 1995). Based on its germination requirements, pond apple has the potential to spread across much of northern Australia and as far south as the northern rivers region of New South Wales (WONS Pond Apple Strategic Plan 2001).

2.3 Altitudinal range

Of the 922 pond apple sites identified in this study, 876 or 95 percent were between sea level and 20m altitude in locations generally subject to inundation from floodwaters. Several higher altitude pond apple infestations were located at Kuranda (360m), Paddy Creek (near Davies Creek) in the Mareeba area (640m), at the top of Liverpool Creek, near Japoonvale (80m), North Maria Creek north of El Arish (60m) and Digger Creek at El Arish (40m). The pond apple occurrences at the top of Liverpool Creek (see **Image 2**) and those around Kuranda were confined to creek banks and perched swamps that would not normally be classed as flood prone areas. All the higher altitude infestations were located in areas used for a variety of agricultural purposes, such as tropical fruit farming.

2.4 Seed Dispersal

Pond apple seed may be dispersed by a number of vectors including water, humans and native and feral animals.

2.4.1 Water dispersal

Water is the main dispersal agent for both pond apple fruit and seeds. Stream flow and tidal characteristics combine as the major influences on the pattern of spread of pond apple within a catchment. The movement of pond apple seed is greatly affected by the morphology or shape of a river, its depth and the velocity of the current. Pond apple generally establishes on suitable soils in depositional areas of slow river current. This can occur at the confluence or junction of two watercourses or where watercourses flow into swamps or where fast-flowing mountain streams slow as they reach the coastal plain.

The areas within the Wet Tropics that have the most dynamic populations of pond apple are at the confluences of the Russell and Mulgrave Rivers and the North and South Johnstone Rivers. In these areas there are high densities of mature pond apple. Confluences of rivers in both the above examples are near river mouths with seed dispersal also being under the influence of daily tidal events. These tidal events result in the transport of pond apple seed both downstream and upstream of parent trees. Because the flow rates of the rivers differ, the movement of seed from one river system to the other varies as the flow rates change throughout the year. Seed dispersal in the Wet Tropics is assisted greatly by regular, but variable, flood events.

In general, it was observed that seeds were deposited on the outer bends of watercourses where floating debris normally accumulates. Good examples of this pattern of dispersal were found along the Daintree River and although seedlings that establish under these circumstances are often washed away in wet season floods, those that survive to maturity are thereafter resistant to flood events.

It was observed that pond apple was generally absent from steep-banked rivers and streams. In places where seedlings do establish it was observed that they are usually destroyed during times of high and fast water flow (see **Image 3**). An example of this pattern of establishment was observed in the upper reaches of Diggers Creek near El Arish, where there were large pond apple infestations, but where the creek formed deeper channels in its lower reaches, fewer trees could be seen.

Pond apple is dispersed most efficiently in river systems that have a broad floodplain. Pond apple seed does not germinate in water *per se* but only after it has been deposited and the flood basin has drained. Pond apple seeds that are distributed by flood events are characterised by patches of similar size/age class trees. Good examples of this in the Wet Tropics include the Eubenangee Swamp and Murray River basins (see **Image 4** and front cover).

Many of the swamps associated with the flood basins of watercourses in the Wet Tropics have been artificially drained using a network of excavated channels. These agricultural drains redirect water into areas too wet for agriculture, or into larger drains that flow into the main river channel. The edges of remnant swamps provide suitable niches for the germination of pond apple seed while the drains themselves provide ideal habitat for pond apple establishment and growth (see **Image 5**). Examples of pond apple infested drainage basins include the Eubenangee Swamp/Canal Creek/Alice River system, the extensive drains constructed at Bamboo Creek west of Innisfail and the Murray River, west of Edmund Kennedy National Park.

The placement of infrastructure can also affect the flow of watercourses and hydrology. Embankments can change the flow rates of watercourses, cause ponding of water and create artificial swamps which are all ideal pond apple habitats. Examples were observed at the top of Dinner Creek (east of Eubanenangee Swamp) and in Victory Creek (North Johnstone catchment) where networks of road and rail embankments have restricted creek flows creating water logged areas that have allowed pond apple to flourish.

In areas of tidal influence seed is spread by the constant ebb and flow of the tide. Tidal areas generally have a greater mix of pond apple age/size classes than areas mainly influenced by flood events. Examples were observed along Bailey Creek in the Daintree, and the Russell, Mulgrave, and Johnstone Rivers.

Although pond apple can establish in saline conditions, it was noted that at the mouths of major rivers such as the Daintree and Russell-Mulgrave Rivers, the density of pond apple declines markedly, presumably due to the effect of salt water. It was observed that pond apple occurred along river banks under freshwater influences and as the water became tidal and the salt content increased, infestations were no longer found in the main river channel, but in the back flows and swamps. Baker, Dorney and Hammer (1995) reported in their trials that although saline conditions greatly reduced pond apple germination, established pond apple trees display a high degree of salt tolerance. Although pond apple can tolerate salinity and occurs in association with some mangrove communities, especially within the Tulip Mangrove (*Heritiera littoralis)* zone, they generally occur infrequently and tend to be of an even age/size class. This may indicate that the establishment of pond apple in these situations is linked to major flood events when soil salt concentrations are temporarily lowered. It was also observed that seedlings which establish along the foreshore do not usually survive long-term in these conditions (see **Image 6**).

Ocean currents also play a major role in the distribution of pond apple along the coast. The longshore flow carries seed washed out of river systems northwards up the coast. Beaches with a south-easterly aspect are more likely to have accumulations of seed due to the prevailing winds and ocean currents, but seeds can be found along most beaches north of the Murray River. The large quantities of seed that wash up onto beaches and germinate normally do not survive for long in these environments. When tide surges or king tides deposit seeds at the back of the beach or into small annual streams they may survive past the seedling stage. Most trees observed in these situations were small and many of those reported to occur could not be relocated. It is considered they may have been lost to moving sand, exposure to salt air, or by the lack of adequate soil moisture.

2.4.2 Seed dispersal by animals

A review of the distribution of pond apple suggests that the spread of seed by animal vectors is very minor compared to its dispersal by water. Seed dispersal by animals appears to be short-distance, within a localised area and largely confined to areas already infested. Although it has been shown that both feral pigs (*Sus scrofa*) and cassowaries (*Casuarius casuarius*) eat pond apple fruit and can travel long distances with viable seed within their gut (Setter 2002), it would generally be expected that most seed would be passed from these animals within the immediate area of the trees on which they have fed.

QPWS rangers in the Innisfail district have reported the existence of isolated occurrences of pond apple in upland areas such as the Basilisk and Graham

Ranges. These isolated trees are most likely to have grown from seeds deposited by pigs or cassowaries and are unlikely to pose any long-term problem as they occur well outside their preferred habitat. However, it should be noted that where these isolated trees could be located they were destroyed.

There does, however, appear to be strong evidence of a link between pond apple distribution and the movement of flying foxes. During the course of this project the project officer received numerous reports from QPWS staff and the general public that flying foxes transport pond apple seed (as they do with mango fruit). These anecdotal observations are supported by the presence of flying fox populations at many of the sites where pond apple occurs such as along the Mossman River, Kuranda, Eubenangee Swamp and the Innisfail Town Swamp (Garnett, Whybird and Spencer, 1999). Pond apple was also observed growing in the understorey near flying fox colonies at Deeral landing, Warrami Lakes at Innisfail and near the Daintree Ferry.

While inspections of flying fox colonies at Gordonvale and Yorkeys Knob did not find any pond apple, it is possible the Gordonvale flying fox colony may be only newly established (the site is not listed in Garnett, Whybird and Spencer, 1999) while the Yorkeys Knob colony is not located in an area where pond apple would otherwise easily establish.

The occurrence of mango trees and pond apple along Skeleton Creek in Cairns and at Marrs Creek near Mossman may also demonstrate a link with flying foxes. Ripe pond apple fruit has a strong aroma that attracts flying foxes but the fruit falls from the tree as soon as it is ripe. Consequently there is only a limited time when flying foxes would find the fruit on the tree palatable.

It should be noted that flying foxes and pond apple both occur in the coastal lowland swamps of north Queensland and any association may merely be that they both prefer the same habitat. No research has been done to determine if there is a positive link between flying foxes and pond apple distribution and dispersal, however, it is considered worthy of further investigation.

2.4.3 Seed dispersal by humans

Pond apple was initially introduced to the region as a fruit tree or as rootstock for custard apples in house gardens, farms and orchards. Most infestations can be traced back to those original horticultural ventures. For example, the infestations in the upper reaches of Maria and Digger Creeks near El Arish have been attributed to previous farming enterprises in the old soldier settlement areas.

2.5 Indicator Species

Pond apple is associated with a range of vegetation types and consequently with many different plant species. However, as pond apple prefers damp, waterlogged areas, native species associated with high soil water content can be used as indicator species to assist in locating possible outbreaks.

Native moisture-loving plant species often found in association with pond apple infestations include:

- **Coast Cottonwood** (*Hibiscus tiliaceus*) is one of the few native plant species that appears capable of out-competing pond apple. It is fast growing, has a spreading habit and forms dense shade. It often forms a screen at forest edges and occupies the type of sites that pond apple also prefers.
- **Macaranga** (*Macaranga inamoena)* has been recorded at nearly all the locations where pond apple occurs, from disturbed melaleuca forests to an understorey species in mature pond apple thickets.
- **Paperbarks** *(Melaleuca spp.)* occupy the same niche as pond apple. While healthy fully developed melaleuca communities rarely contain pond apple, disturbed sites are easily infested. This disturbance can be the result of logging, clearing or natural events such as cyclones where additional light from a broken canopy promotes pond apple germination and establishment.
- **Tulip Mangrove** (*Heritiera littoralis*) occurs at the inland limit of mangroves. This species can also be used to indicate the presence of pond apple.

A number of other weed species are often associated with pond apple and are good indicators of the potential presence of pond apple. These often occur in clearings or areas of substantial disturbance such as along drainage lines and include:

- **Singapore Daisy** (*Sphagneticola trilobata*) is a species which has spread throughout the Wet Tropics particularly along the banks of rivers and drains.
- **Hymenachne** (*Hymenachne amplexicaulis*) this introduced grass species is particularly prevalent in the Tully-Murray river basin.
- **Mango** (*Mangifera indica*). There is a possible link between naturalised mango trees and pond apple infestations, especially north of Gordonvale. It is thought this phenomenon may be linked to the possible dispersal of pond apple seed by flying foxes.

2.6 Ecosystems invaded

Analysis of the current distribution of pond apple using GIS techniques show a relationship with certain vegetation types. These vegetation types are listed in **Tables 2 and 3** below.

The ecosystems listed in **Table 2** occur on coastal lowlands within the project area. The two known outbreaks of pond apple on the Atherton Tablelands occur within the ecosystems listed in **Table 3**.

Table 2: Coastal ecosystems at risk from pond apple invasion

Description of vegetation type	Stanton & Stanton[1]	Regional Ecosystem[2]	Susceptibility
Rainforest Types			
Disturbed rainforest communities	Ra	-	High
Complex mesophyll vine forest on very wet basalt soils. On disturbed areas.	B1ax	7.8.01	High
Complex mesophyll vine forest on very wet basalt soils. On heavily disturbed areas.	B1ax(h)	7.8.01	High
Mesophyll vine forest on very wet granitic, metamorphic and alluvial soils. On disturbed areas.	A2ax G2ax M2ax	7.3.10 7.12.01 7.11.01	High
Mesophyll vine forest on very wet alluvial soils. On heavily disturbed areas.	A2ax(h)	7.3.10	High
Mesophyll vine forest on very wet alluvial soils with high wind disturbance	A2ax(w)	7.3.10	High
Mesophyll vine forest dominated by, feather-leaf (*Archontophoenix*) palm swamps on very wet alluvial soils.	A3a	7.3.03	Moderate
Mesophyll vine forest dominated by feather-leaf (*Archontophoenix*) palm swamps on very wet alluvial soils. On disturbed areas.	A3ax	7.3.03	High
Highly disturbed areas that originally supported rainforest vegetation, but whose original vegetation type is not obvious from the present structure and/or species composition of the vegetation. Occurs on soils of metamorphic origin.	M28x(h)	-	High
Mesophyll vine forest on seasonally inundated alluvial soils with feather palm (*Archontophoenix alexandrae*) common in the sub-canopy.	A72	7.3.10	Moderate
Mesophyll vine forest on seasonally inundated alluvial soils with feather palm (*Archontophoenix alexandrae*) common in the sub-canopy. On disturbed areas.	A72x	7.3.10	High
Sclerophyll woodland and forest types			
Disturbed sclerophyll woodland or forest	Rs	-	High
Open to closed forest dominated by *Acacia celsa*. Very wet and wet foothills, uplands and highlands on alluvial soils.	A12a	-	Moderate

Description of vegetation type	Stanton & Stanton[1]	Regional Ecosystem[2]	Susceptibility
Sclerophyll woodland and forest types			
Low to medium *Eucalyptus pellita*, *Corymbia intermedia, Melaleuca dealbata* woodland with vine forest understorey on alluvial soils. On disturbed and highly disturbed areas.	A16gvx A16gvx(h)	7.3.12	High
Medium to tall open *Eucalyptus tereticornis* forest and woodland. Includes communities ranging from those dominated by *E. tereticornis* and mixtures of that species with Corymbia *intermedia*, *Eucalyptus crebra*, *Lophostemon suaveolens* and *Allocasuarina torulosa*. Occurs on granitic soils in disturbed areas.	G32vx	7.12.29	High
Low to medium *Melaleuca quinquenervia* woodland and forest. Poorly drained alluvial soils of the coastal lowlands. Occurs in ± disturbed areas with vine forest or shrub understorey.	A33 A33sx A33v A33vx A33x	7.3.05	High
Medium to tall *Melaleuca quinquinervia* woodland and forest. Occurs in disturbed dune areas with vine forest understorey.	D38vx	7.2.03	High
Medium to tall open *Corymbia intermedia* forest with a vine forest understorey. On dunes.	D73v	7.2.03	Moderate
Medium open *Eucalyptus pellita and Corymbia intermedia* forest and woodland. Poorly drained alluvial soils, including seasonal swamps.	A80s	7.3.07	Moderate
Medium open *Eucalyptus pellita and Corymbia intermedia* forest and woodland. Occurs on dunes on disturbed areas.	D80x	7.3.07	High
Medium *Melaleuca viridiflora*, and *Lophostemon suaveolens* woodland.Poorly drained alluvial soils of coastal lowlands.	A118sx	7.3.08	High
Highly disturbed areas that originally supported sclerophyll vegetation, but whose original vegetation type is not obvious from the present structure and/or species composition of the vegetation. Occurs on metamorphic and alluvial soils.	A29x(h)	-	
Vegetation complexes and			

Description of vegetation type	Stanton & Stanton[1]	Regional Ecosystem[2]	Susceptibility
mosaics			
Complex of open to closed shrublands, grasslands and low to medium woodlands and forests. Includes pure stands of *Casuarina equisetifolia*, and open to closed woodlands dominated by *Acacia crassicarpa*, *Syzygium forte* subsp. *forte*, and *Calophyllum inophyllum* and *Pandanus* spp. Generally confined to foredunes.	D44	7.2.03	Moderate
Saline littoral zones			
Mangrove forest, *Rhizophora spp*. *Bruguieria spp*. Occurs on saline alluvial soils.	A22a	7.1.1	Moderate
Mangrove forest, *Rhizophora spp*. *Bruguieria spp*. Occurs on saline alluvial soils on disturbed areas.	A22ax	7.1.1	High

1. Stanton & Stanton (in prep.).
2. Environmental Protection Agency (2003). Regional Ecosystem Description Database (REDD). Version 4.0. Updated September 2003.

Table 3: Atherton Tablelands ecosystems containing pond apple

Description of vegetation type	Stanton & Stanton[1]	Regional Ecosystem[2]	Susceptibility
Mesophyll vine forest on very wet alluvial soils. On disturbed areas	M2ax	7.11.01	High
Medium to tall open *Eucalyptus tereticornis* forest and woodland. Includes communities dominated by *E. tereticornis* and mixtures of that species with Corymbia *intermedia*, *Eucalyptus crebra*, *Lophostemon suaveolens* and *Allocasuarina torulosa*. Occurs on granitic soils in disturbed areas.	G32vx	7.12.29	High
Highly disturbed areas that originally supported rainforest vegetation, but whose original vegetation type is not obvious from the present structure and/or species composition of the vegetation. Occurs on metamorphics.	M28x(h)	-	High

1 Stanton & Stanton (in prep.).
2. Environmental Protection Agency (2003). Regional Ecosystem Description Database (REDD). Version 4.0. Updated September 2003.

It should be noted that the vegetation types listed in **Table 3** were not targeted in this project as they are covered under another NHT project (refer **Table 1 Component 3A**).

Healthy, undisturbed ecosystems appear able to resist the establishment of pond apple, possibly due to low light conditions on the forest floor. The GIS analysis emphatically showed that pond apple has a distinct preference for establishment in disturbed ecosystems (shown in the tables by an "x" in the Stanton & Stanton codes). Two factors appear to be the major determinants of pond apple presence in the Wet Tropics. These are flood prone areas and cyclone damaged vegetation. Both floods and cyclones typically occur between December and April which corresponds to the period when pond apple seed is at its peak availability and viability.

There has been very little human disturbance to the native vegetation at the mouth of the Russell River and its large pond apple infestations appear to have been the result of the disturbances caused by cyclone Agnes in 1956. Some infestations found near Innisfail appear to be related to the impact of cyclone Winifred in 1986, compounded by an array of human agricultural impacts on the natural vegetation and hydrology. Unfortunately, determining and separating various causal factors in the present day distribution of pond apple requires a reliable method for aging pond apple trees. Swarbrick (1993) noted that pond apple trees are difficult to age as multiple growth rings may be laid down in any one year. More work is required on the ageing of pond apple to better understand the role of floods, cyclones and humans in its spread.

One of the aims of this project was to prioritise pond apple control program trials to those regional ecosystems officially considered as endangered. The following regional ecosystems are listed as endangered in Sattler and Williams (1999) [3].

- 7.3.12 - **Forest red gum** (*Eucalyptus tereticornis*) woodland on very wet, to wet well drained lowland alluvial soils.
- 7.3.22 - **Complex mesophyll riparian vine forest** on moist and dry well drained lowland alluvial levees.
- 7.3.7 - **Coastal floodplain forest red gum/melaleuca** (*Eucalyptus tereticornis/Melaleuca spp*.) open forest complex on moist to very wet poorly drained lowlands.
- 7.3.6 - **Swamp paperbark** (*Melaleuca quinquenervia*) open forest/vine forest Complex on a variety of very wet poorly drained lowlands.
- 7.3.3 - **Alexandra palm** (*Archontophoenix alexandrae*) swamp vine forest on very wet poorly drained fertile lowlands.

The endangered ecosystems listed above were found to be dispersed throughout many catchments and focussing control efforts purely on a regional ecosystem basis was considered to be an ineffectual approach as reinfestation from another part of the catchment would occur. Control work was therefore undertaken at a whole of catchment level rather than on an individual regional ecosystem basis.

[3] It is important to note that compilation of the information about regional ecosystems presented in Sattler and Williams was derived from a range of information sources and the endangered ecosystems listed were derived from 1999 data. During the past few years the Queensland Herbarium has developed a program for the systematic mapping of regional ecosystems across Queensland. This has resulted, and will continue to result, in updates to the descriptions and status of regional ecosystems which are maintained by the Herbarium in their Regional Ecosystem Description Database.

3. Mapping existing and potential pond apple distributions

3.1 Mapping existing distribution

Infestations were located, inspected and mapped from Coopers Creek, near Cape Tribulation in the north to the Murray River, near Cardwell in the south (refer **Map 2**). Although within the Wet Tropics bioregion, areas to the south of Cardwell were not included in this project. Pond apple is not known to occur in the Cardwell area, but it is possible that pond apple could be found further south in the Ingham area. The most westerly infestation found was at Paddy's Creek east of Mareeba.

The major Wet Tropics river catchments were divided into their component sub-catchments to aid in the mapping of pond apple distribution Sub-catchments were also considered to be effective management units for implementing a control program (refer **section 4**).

3.1.1 Field mapping

It was the aim of the project to visit all reported pond apple infestations in the study area and to map and record pond apple distribution in a consistent manner at all sites. Sites that were not visited but had reliable sources were also included in the mapping. A classification code (refer **section 3.1.2** below) was used to describe the mapped pond apple infestation and was also incorporated into a GIS database.

3.1.2 Electronic mapping

Recording of GPS Points

Some 900 GPS points were recorded while conducting initial field inspections. Further GPS points and tracks were also recorded during subsequent fieldwork. This data was used to define the exact area of work covered and to formulate costings for control work.

All GPS information recorded in the field was down loaded onto a computer through "Waypoint+", saved as "delimited text files" and plotted through the Esri GIS program "ArcVeiw 3.2". The GPS datum used was the WGS84, Universal Transverse Mercator Grid 55, with coordinates being Eastings and Northings. GPS points recorded in the field were also given a letter code to describe the infestation (refer **Appendix 1, Table A1**).

GIS mapping

GPS points were plotted onto "ArcVeiw 3.2" using a 1:100 000 topographic map base layer. Plotted points provided an indication of the density of trees and were analysed against other site details derived from additional data layers.

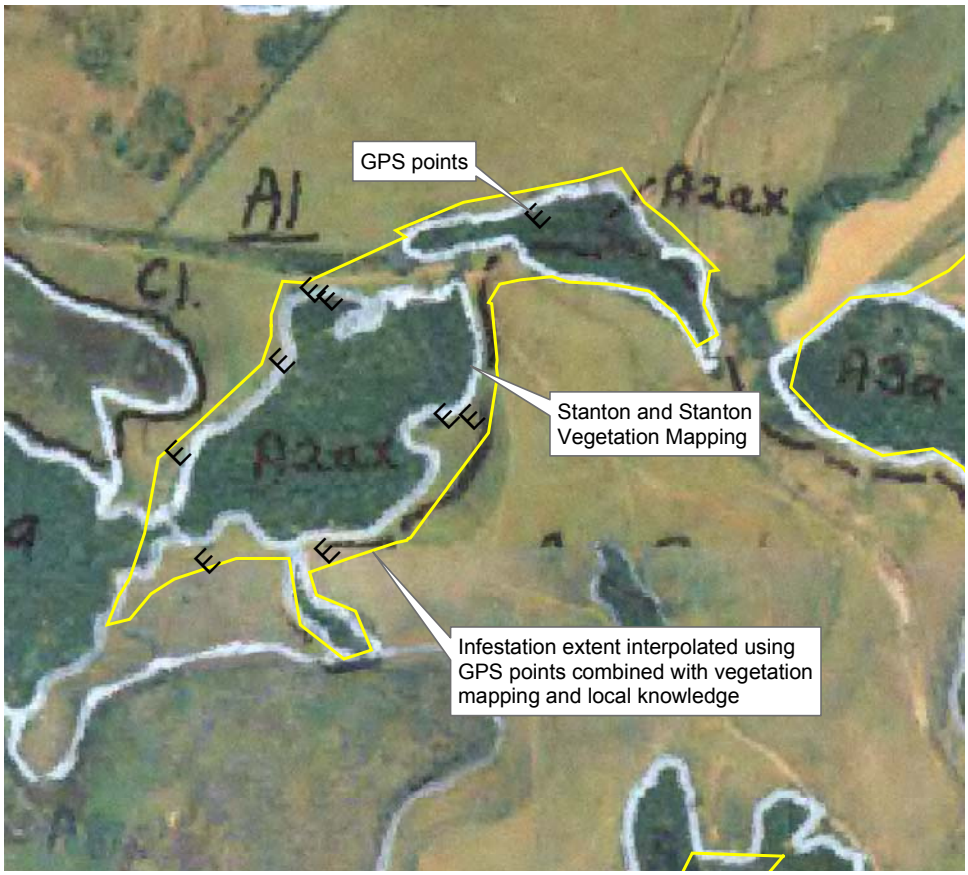
GIS software was used to convert the GPS point data to polygons showing areas of existing infestations. These polygons were then saved as shape files in ArcView. A 1:5 000 scale image was used to analyse the vegetation mapping and create the shape files. These shape files were also used to analyse the distribution of pond apple against other data layers such as vegetation types, watercourses and roads. Shape files also have attached data

tables allowing additional detailed information to be recorded for individual polygons (refer **Appendix 1, Table A2**).

The *Vegetation Mapping of the Wet Tropics Bioregion* (Stanton & Stanton (in prep.) provided the detailed vegetation base mapping for this project. This mapping identifies disturbed vegetation or where the structure of the vegetation has been significantly altered. As discussed previously ecosystem disturbance is a major indicator of the potential for an area to be invaded by pond apple.

Aerial photos were also used to assist in mapping the extent of distribution of dense stands (refer **Figure 1**). Dense stands have an even textured and uniform coloured air photo signature and are relatively easy to identify. This method was only used for mapping once the presence of pond apple was visually confirmed in the field.

Figure 1: Example of aerial photography with vegetation and geology delineated by *Stanton & Stanton* (in prep.) and GPS points plotted to form extent of known infestation



3.1.3 Daintree aerial investigation

At the time of this study the *Vegetation Mapping of the Wet Tropics Bioregion* (Stanton & Stanton, in prep.) was not completed for much of the Douglas Shire. Given the difficulties associated with access to the coastal parts of the Shire, it was considered necessary to undertake an aerial survey. Peter Stanton (external consultant) and Bob Jago (Douglas Shire Council Environment Officer) conducted this survey on the 21 August 2003. The survey was timed to coincide with pond apple's deciduous phase so that trees would be easier to identify. GPS points collected during this aerial survey confirmed known locations and assisted to define the limits of other infestations.

3.1.4 Extent of existing infestations

The pond apple mapping identified 2,051 hectares of the Wet Tropics bioregion currently infested by pond apple. The locations of these infestations are shown in **Maps 3 – 10** at the end of this report.

The largest area infested is within the Canal Creek/Alice River catchment (Canal Creek drains into Eubenangee Swamp and Alice River connects the swamp to the Russell River). The area is a large flat basin filled with permanent swamps and sedgelands. The swamp fills with water annually during the wet season and periodically during floods. It also has a restricted out-flow and retains water within the basin for extended periods. Eubenangee Swamp is an area within the bioregion that most closely replicates pond apple's natural habitat, the Florida everglades.

The next largest infestations are within Baileys Creek, north of the Daintree River and along the Murray River, south of Tully. These larger areas all occupy flood basins that periodically fill with water.

The smaller areas of infestation are located along creek banks. These linear areas are much smaller than the larger flood basins, with seed spread mostly within the confines of river channels.

A brief description of each pond apple infestation and the control work carried out within sub-catchments is provided below. Sub-catchments are listed from north to south.

- **Baileys/Coopers Creeks:** This well-developed infestation will continue to spread on each flood event. Douglas Shire Council and QPWS have done some control, particularly in the southern part of the infestation, using funds provided under Component 3B of this overall project (refer **Table 1**) and previously with other funding (refer **Map 3**).

- **Daintree River:** This infestation is one of the largest in the Wet Tropics and is still spreading, with trees found throughout the flood basin but in localised patches. This area together with Bailey and Cooper Creeks has been the focus of Douglas Shire Council control works over the 2002/2003 year. It is believed that the infestation can be controlled with on-going treatment (refer **Map 3**). Control has also been funded under Component 3B of the overall project (refer **Table 1**).

- **Mossman River:** This infestation consists of isolated trees and is at an early stage of development (refer **Map 3**). The Douglas Shire Council is controlling it. Its source is unknown.

- **Barron River:** Infestations occur primarily along Jumrum Creek, a tributary of the Barron near the township of Kuranda. These infestations probably established from neglected gardens or orchard trees and are small in comparison to coastal infestations. The size of this infestation is increasing but may never reach its full potential because of its location at 95m above sea level and because the area has no periodically flooded basin. The Kuranda infestation and a small infestation at Paddy Creek has been eradicated by Mareeba Shire Council under Component 3A (refer **Table 1**) of this overall project. There are also isolated occurrences at Kamerunga on the lower Barron River (refer **Maps 4 & 5**).

- **Trinity Inlet:** The two major infestations are at Skeleton Creek near White Rock and at East Trinity. There are also various sites around Trinity Inlet and reported sightings in the Cairns Central Swamp. The Cairns City Council has controlled infestations in Skeleton Creek, in the section west of the Bruce Highway. East Trinity has a rapidly developing infestation within the bund wall with some control work in this area carried out under this project (refer **Map 6**).

- **Mulgrave River:** One of the Mulgrave River catchment infestations was found along Hemming Creek at Gordonvale. This small infestation originated from a neglected garden. Control work was carried out in conjunction with the Mulgrave Landcare group funded by this project. The lower reaches of the river have large infestations sustained by the periodic flooding of the Mulgrave and Russell Rivers. These infestations are well developed and will continue to spread, especially into any new areas of disturbance (refer **Map 6**).

- **Russell River:** There are well-established, large infestations on the lower reaches with the worst affected area located around Russell Landing. This infestation is likely to expand since it is fed from Norries, Alice and Dinner Creeks. The only control work undertaken has been uncoordinated and by local landholders (refer **Maps 6 & 7**).

- **Norries Creek:** A recent infestation in the upper reaches of the Russell River, possibly from a failed custard apple orchard. The whole of the area that is suitable for pond apple establishment is infested. There has been no control work undertaken. This system along with Alice and Dinner Creeks need to be controlled before any effective work can be done in the lower reaches of the Russell or Mulgrave Rivers (refer **Map 7**).

- **Canal Creek/Alice River:** These waterways feed into Eubenangee Swamp which is the site of one of the largest infestations of pond apple in the Wet Tropics. Control of pond apple by QPWS staff within Eubenangee Swamp National Park has been ongoing for the past 10 years. The recent work is an extension of that previously undertaken by QPWS and has concentrated on creeks draining into the swamp. The park is a large basin and collects seed that is brought in during flood events. The area includes Nigger and Dinner Creeks and their catchments, which are tributaries of the Alice River (refer **Map 7**).

- **Victory Creek:** This creek has a well established and expanding population that supplies seed into the North Johnstone River. Landholders have undertaken limited control work (refer **Map 7**).

- **North Johnstone River:** The lower reaches of this river contain well-established pond apple populations contained by the area's topography. Seed is regularly re-supplied from Victory Creek, Sweeney Creek and from the Warrina Lakes area. As seed is continually being dispersed down-stream these infestations can only be controlled in conjunction with those of the South Johnstone River, Bamboo Creek and Ninds Creek. The Johnstone Shire Council has carried out some control work in Innisfail (refer **Map 7**).

- **Stone Creek:** There are some minor infestations from the flood overflow of the North Johnstone River and some movement of seed by animals.

No control work has been undertaken in the area but it can be done in isolation from the North Johnstone River (refer **Map 7**).

- **South Johnstone River:** There is a large, well-established infestation on Bamboo Creek which will continue to expand and supply seed to down-stream areas. Limited control has taken place through the Innisfail town area along river banks (refer **Maps 7 & 8)**.

- **Ninds Creek:** This is possibly the most advanced infestation in the Wet Tropics. Only a few areas do not contain pond apple and any disturbance in the area results in the rapid invasion by more pond apple. Some control has occurred in Clancy Park by the Johnstone Shire Council and the Catholic Diocese of Innisfail (refer **Map 7**).

- **Moresby River:** There are two locally, well-established populations in this catchment; one at the northern end of the river and the other on Moresby creek. The northern infestation occurs low in the catchment and is contained by its close proximity to the limit of tidal influence. The Moresby Creek infestation is developing quickly and if the landholder ceases to periodically control the trees on his sugar cane farm it will quickly invade the remainder of the creek and extensive wetlands (refer **Map 8**).

- **Liverpool Creek:** This infestation is well established in the upper reaches, however, except for very isolated occurrences, it does not extend far downstream. The Johnstone Shire Council undertook control programs using funds provided by this project (refer **Map 8**).

- **Big Maria Creek:** A relatively young infestation confined to the upper reaches of Diggers Creek near El Arish. This area includes North Maria Creek where an infestation has now been controlled as part of this project. Johnstone Shire Council was provided with funds from this project through a Memorandum of Understanding to complete this task. This work builds on the control undertaken at Liverpool Creek and links with work done by QPWS in Kurrimine National Park.
  Extensive areas of high susceptibility, no infestations verified at South Maria Creek (refer **Map 8**).

- **Murray River:** The main area of infestation is located in a large flood basin in the mid-reaches of the river. It would appear that seed is primarily transported during flood events and this infestation is still developing. Control work along Warrami and Cherrin Creeks and to the west of the Murray River has been funded by this project. A dedicated approach to pond apple control in this catchment would probably result in its eradication (refer **Maps 9 & 10**).

- **Coastal Beaches:** This includes the Cairns Northern Beaches, Bramston Beach, Cow Bay, Ella Bay, Hartleys Creek, Mission Beach, Port Douglas, Wonga Beach and Yarrabah. Most coastal beaches contain short-lived pond apple seedlings growing above the high tide mark. However, seedlings that establish between the swales behinds the dunes may survive to maturity. Very large quantities of seed are typically found on the beaches to the north of infested river systems. When conditions are favourable (refer **section 2**) these seedlings can germinate *en masse* (refer **Image 6**). Local conditions usually prevent these from surviving (refer **Maps 3, 4, 6, 7, 8, & 10**).

- **Offshore Islands:** Pond apple seedlings and the occasional well-established tree have been reported on most offshore islands along the Wet Tropical coast. If recognised as pond apple, most are eradicated.

- **Unconfirmed reports:** Although there are reports of pond apple occurring in the Ingham district a limited search of the area has failed to find any infestations. Many parts of the Ingham district would be highly susceptible to invasion (not mapped in this project).

Within the above catchments, pond apple was found in 60 named creeks. These are detailed further in **Appendix 2**.

3.2 Predictive mapping

To accurately predict the occurrence of pond apple, spot location data in the form of GPS points were analysed with the recent vegetation mapping by Stanton & Stanton (in prep.).

The vegetation types at recorded GPS locations were used to produce a list of vegetation units that currently have pond apple infestations (refer **Tables 2** and **3**). Once the vegetation units were known, their total remaining distribution within the project area was mapped.

These maps showed that susceptible vegetation covered a range of landforms. However, as 95% of the recorded distribution of pond apple was found below 20 metres in altitude, this factor was used to refine the predictive mapping (i.e. only vegetation below the 20 metre contour is shown in the predictive mapping).

Since pond apple was shown to prefer disturbed sites, and since the vegetation mapping (Stanton & Stanton, in prep.) distinguishes between disturbed and undisturbed vegetation, this factor was also used to identify those areas with a ‘high’, as opposed to a ‘moderate’, susceptibility to pond apple invasion.

Field-validation of the predictive maps has shown them to be an excellent predictor of pond apple infestations, with denser stands found in the high susceptibility areas and isolated trees found in the moderate areas. However, it is important to note that it was logistically and financially impossible to inspect all susceptible areas identified, and that the predictive pond apple mapping although of a high precision is not definitive.

3.3 Areas susceptible to pond apple invasion

Predictive mapping of potential pond apple habitat identified 15,363 hectares as highly susceptible to invasion and 27,973 hectares as moderately susceptible (refer **Maps 3-10**). It is important to note that the predictive mapping is based on existing native vegetation units. As this does not include cleared areas, the area considered susceptible to infestation is an underestimate.

Based on these figures, it is estimated that only about 4.7 percent of the total area potentially suitable for pond apple invasion in the Wet Tropics is currently infested. Further investigation is required to ascertain a more accurate extent of current infestation.

3.4 Mapping control sites

Areas where control work was undertaken were inputted into the GIS from data registered on field maps or from GPS recordings. By using a belt mounted GPS it was possible to automatically record a series of points showing the movement of the wearer. The track points were supplemented by recording waypoints at the edges of work areas or at geographical locations. The data was later downloaded and plotted in ArcView.

From this information polygons could be drawn providing both an accurate measurement of the area where control work had taken place and also where to resume work at a later date. A coded classification system was developed to describe polygons where control work occurred. Codes included information on date work was done and who undertook work (refer **Appendix 1, Table A3)**.

4. Planning a pond apple control program

4.1 Catchment planning

Since water is the main dispersal agent for pond apple seed, the key to successful eradication is to start at the top of the catchment and work down stream. Follow-up treatments are significantly reduced by the removal of any upstream source of seed. Because of the relatively short viability of pond apple seed, eradication of pond apple from a site is usually possible within 3 years if re-seeding can be prevented.

4.2 Prioritising areas within catchments for control

Prioritising areas for control can be based on the size of an infestation and the level of resources required for project completion. Large projects requiring several years of return treatments should be broken down into smaller, more manageable areas. To ensure fresh seed is not being transported into previously controlled areas, the upper catchment watercourses should be targeted in the first project, followed by control work in the flood plain, with tidal areas being treated last.

Pond apple infestations can be categorised by the state of their development within the whole catchment.

- **Established populations:** Infestations that are widely spread throughout a catchment. Seed reserves are readily dispersed after disturbance or control work effectively maintaining the infestation. Examples may be found along the Johnstone River and at Eubenangee Swamp.

- **Establishing populations:** Trees that are spread unevenly through a catchment. Seed is only able to disperse during major flood events occurring in exceptionally wet years. Infestations are characterised by small-localised thickets. Examples may be found along the Daintree River and Liverpool Creek.

Catchments where populations are still establishing should be given high priority for control, as resources to control an establishing population are significantly less than the cost to control larger, well-established populations.

4.3 Catchment units for management control

It is considered that effective planning for the management of pond apple requires the division of a region into primary river catchments and then secondary creek catchments. The secondary catchments can be further broken down on an individual creek or drain basis as required. These management units allow an effective, natural, hierarchical approach to control planning.

For large flood basins there may be the opportunity to divide the basin into smaller work areas based on the probability of 20, 50 or even 100-year flood events. The effectiveness of a control program within a flood basin will depend on the amount of resources available to eradicate an existing outbreak while reducing the possibility of the site being reinvaded from an external seed source.

When planning control programs the last areas to consider are those that are influenced by the tide. Due to more active seed movement (dispersal can be as

frequent as twice daily) these areas may be highly susceptible to reintroductions. Control in these areas should only be considered after all upstream seed sources have been eradicated.

4.4 Preparation of a risk management plan

Any control program needs to include a work place risk management plan for the safety of workers. This is particularly important in coastal environments where pond apple and crocodiles prefer the same habitat. In these circumstances great care needs to be taken especially during the crocodile-breeding season from September to April.

4.5 Timing of control work

The ideal time to control pond apple is during the dry season from August to November as this is the time of the year when access to the wetter areas of the catchment is easiest. Control done during the dry season also ensures that most trees are killed before the fruiting period, which reduces the amount of seed added to the soil seed bank.

Pond apple trees in drier areas, or in drier years, produce significantly less fruit compared to trees in wetter areas or in wetter years. In drier catchments it is often possible to eradicate pond apple without the need for follow up work, so additional work undertaken during drier years can greatly assist a control program. Conversely, a good wet season will produce significantly more fruit and seed is more likely to be spread in the wetter seasons.

Great care must be taken to control every tree no matter how small. One missed tree can potentially re-seed an entire area and negate much of the effort expended during a previous control program.

4.6 Monitoring control effectiveness

In any control work it is probable that some trees will be missed, especially in the case of ‘multi-stemmed’ pond apple trees.

It is recommended that monitoring be conducted in the year following the control program to ascertain if follow-up eradication is required. Flood basins should be closely monitored as they are almost certain to require further follow-up work.

The majority of pond apple seed is viable for less than 2 years (Setter 2002) and since pond apple starts to flower at two years of age (Swarbrick 1993) there is a window of two years before any seeds that have germinated after the initial control are mature enough to produce seed. An area can be considered to be free of pond apple if no seedlings are present four years after the last control.

To ensure total eradication the following issues should be addressed:

- Control work should start at the top of a catchment and proceed down stream along watercourses and drainage lines.
- It is preferable to control all infestations within a catchment under the one program to reduce the likelihood of reinvasion by seed from other areas within the catchment.
- All pond apple plants need to be killed, regardless of size.
- The ideal time for control is the dry season (August to November) so all plants that have germinated from the previous fruiting cycle are removed. This will also maximise the amount of seed taken out of the system.
- Monitoring will be required for at least two years after the last plant is killed. It may not be necessary to do control work every year as long as trees are killed before they are old enough to fruit (two years). If no seedlings are recorded four years after the last plant is destroyed an area can be considered free of pond apple.
- If control is done in an area that can be reinvaded, follow-up work will be required every two years until trees in the area providing the seed are eradicated.

5. Control techniques

5.1 Previous studies

Pond apple control programs have been operating in the Wet Tropics for about 10 years and a range of control techniques have been trialled. Herbicide treatment is the most common control technique but mechanical and manual methods are also employed.

The Queensland Department of Natural Resources, Mines and Energy (DNRM&E) have conducted trials to determine suitable herbicides and their application rates for pond apple control. These trials have shown that some coppicing (sprouting from the trunk of the tree) is evident from the base of 10-20cm diameter trees following stem injection of herbicide (see **Image 7**). Studies have shown that most, although not all, trees which coppice following herbicide treatment subsequently die over time.

In the DNRM&E herbicide trials, none of the trees treated with *Glyphosate* showed any coppicing. However, it is important to note that the trees in these trials averaged 8-10cm in diameter. Most of the smaller trees treated with *Tordon* coppiced, but most subsequently died. Some of the larger trees treated with *Tordon* also coppiced with many survivors, which were effectively treated using weaker herbicide dose rates than that listed in the Off Label Registration. In summary, it is expected that larger trees will generally be harder to kill with herbicide than smaller trees.

The findings of the DNRM&E trials suggest that trees over 25 cm diameter should be felled with a chainsaw and the stumps coated with herbicide. Tall trees should be felled where there is risk of injury from dead limbs falling from a poisoned tree. As with all weed control, if plants are left to die *in situ* the amount of weed regrowth is minimised and native plant seedlings have a better chance of recolonising the site. If the ground is disturbed, the weed problem can be worsened. In these areas replanting with desirable plant species is recommended as soon as possible.

5.2 Hand and mechanical control

Smaller trees can be pulled out by hand and in damp conditions plants up to 1.5 metres high can be treated this way. Hand pulled plants need to be up-ended or placed in a fashion that doesn't expose the roots to the damp earth or the plant will re-shoot. For example, uprooted plants can be placed in the fork of a nearby tree.

In situations where pond apple is in dense monocultures their removal by heavy machinery can be a cost effective option. Trees are normally pushed and formed into windrows and burnt. Trees in drains can be dug out and left to rot when the drains are cleaned (the soft wood rots very quickly). Unfortunately, pond apple plants are often cleared and then left mixed with the soil cleared out of the drain or pushed up against standing vegetation. In such cases there will be vegetative regrowth and the area will need further control work.

5.3 Fire

Fire can be an effective control technique under some circumstances. Its effectiveness is related to the intensity of the fire. A mild fire may kill small trees (up to 1.5 metres high) but large trees need more intense and/or more frequent fires. Dense stands of pond apple lack sufficient fuel loads to sustain a fire (Stanton 1998). Usually fire does not kill all seed within the soil so additional work in the form of hand pulling or repeated burning will be required to exhaust the soil seed bank.

Fire is most effective in:

- maintaining melaleuca woodlands free of pond apple;
- removing regrowth in woodlands;
- removing seedling in sedge lands; and
- destroying fallen timber after machinery has been used to clear the pond apple.

It is important to be aware that the use of frequent fires to control pond apple may effect changes to the natural vegetation patterns of an area. Frequent fires reduce closed forest vegetation and result in a change to a more open woodland vegetation pattern, dominated by grasses and fire resistant tree species. More open woodland vegetation is also more susceptible to invasion by pond apple.

5.4 Herbicide use

All control work under this project was undertaken in accordance with the Off Label Registration for herbicide treatment of pond apple. The Australian Pesticides and Veterinary Medicines Authority (APVMA) regulate the use of herbicides in Australia and all herbicides must be registered by the APVMA. This organisation specifies the rates with which each herbicide can be used and its method of application. Since pond apple is not listed on any registered product label, it has been registered “off label” through the APVMA. The Off Label Registration permit number is PER5190 and can be accessed though the National Registration Authority web site www.nra.gov.au. It should be noted that this registration expires on the 31 March 2005. A new permit will be required for herbicide treatment of pond apple once the existing one has expired. No control work should commence before operators read the permit conditions and any other relevant herbicide product labels.

Approved control techniques under the APVMA permit are:

- **Basal bark application**
  Herbicide is mixed with diesel and sprayed or painted to the outer bark of the tree from ground level up to a height of 50cm. This is an effective method but can be unpleasant for the operator. There can also be a risk of soil or water contamination.

- **Stem injection**
  Herbicide is injected into a double row of cuts made with an axe blade as low as possible on the tree. The top row of cuts is spaced horizontally around the tree at an axe blade length apart with the bottom layer of cuts placed under the spaces of the top cuts; this ensures the whole circumference comes in contact with the herbicide.

If this is not done correctly the limbs above the gaps can remain unaffected by the herbicide.

- **Cut stump**
  Herbicide is immediately coated onto the stump of a stem that has just been cut with a brush hook, machete or chainsaw. The cut stump method can be used on trees up to a 10 cm diameter and also those with stem diameters over 25 cm. The cut stems should be coated immediately with herbicide. This is a quick and effective technique, but care is needed to make the cuts as low and as horizontal as possible, to ensue the poison is taken up readily. Care must also be taken to ensure cut stems do not fall to the ground in a way that allows them to propagate vegetatively.

- **Overall spray**
  Trees are folia sprayed. This is useful in situations involving a monoculture where there is no risk of damaging any native species in the vicinity.

The technique used will depend on the size of stems and the number of trees per hectare. Techniques that were found to be the most suitable in different circumstances are listed in **Table 4**.

Table 4: Control technique guide

Tree Size	Dense Stands	Sparse Stands	Isolated Trees
Up to 1metre high	Folia spray	Hand pull	Hand pull
Stem diameter less than 10cm	Cut stump or folia spray (smaller trees in clumps), basal bark.	Cut stump	Cut stump
Stem diameter greater than 10cm less than 25cm	Stem injection, basal bark, Machinery (bulldozer -dense mono cultures only)	Stem injection	Stem injection
Stem diameter greater than 25 cm	Cut stump with chainsaw and coated with herbicide	Cut stump with chainsaw and coated with herbicide	Cut stump with chainsaw and coated with herbicide

5.5 Control equipment

In the past a range of equipment has been used for pond apple control. QPWS have effectively used and recommend the following equipment for pond apple control (See **Image 8**).

- **Philips gun:** an injector gun with a 5.0 ml capacity that can apply small doses of herbicide.
- **Backpack:** a 2.5 litre or 5.0 litre capacity backpack that connects to the Phillips gun, these can be set up to be gravity or pressure fed.
- **Tordon axe:** a small axe with a curved angled head designed for use when stem injecting trees. Hatchets can also be used, but they usually need to have the blade reshaped so the cuts form a pocket in the tree to hold herbicide.

- **Brush hook:** useful for gaining access to sites. A sharp brush hook can cut through trees up to 12 centimetres in diameter.
- **Machete:** some Councils use long bladed machetes. These are used both for cut stump and for forming pockets in larger trees. Care must be taken with larger trees to ensure a deep pocket is formed capable of holding sufficient herbicide.
- **Belt:** a custom made belt to hold the Philips gun and axe while moving through an area. This prevents damage to equipment and protects the user from the sharp edges of axes. These need to be custom made especially for holding axes. Leather is recommended as the most durable material.

5.6 Site rehabilitation and replanting

Leaving treated plants to die *in situ* usually removes the need for replanting with native trees. Most areas invaded by pond apple contain remnant or suppressed native seedlings and once the pond apple trees are defoliated by the herbicide the native seedlings quickly grow.

Replanting could be of benefit immediately after control work using heavy machinery, or where felled trees expose large areas of soil. To date no projects have attempted replanting. The need to replant will be determined by the aims of the project and the type of area controlled.

Although no trial plantings were undertaken in this project (due to time limitations) the following list of species (refer **Table 5**) may be used as a guide if replanting is proposed. The list is based on species that were observed to be able to compete with pond apple in the field. If the pond apple on a particular site can be totally eradicated any species previously occurring in the area is suitable for replanting. These species are usually present as regrowth.

Table 5: Plant species suitable for planting in pond apple control areas

Species	Common Name
Hibiscus tiliaceus	Coast Cottonwood
Pandanus spp.	Screw Palm
Acacia celsa	Brown Salwood
Archontophoenix alexandrae	Alexandra palm
Melastoma affine	Blue tongue
Melaleuca viridiflora	Broad-Leaved Tea Tree
Cyperus spp.	Sedges

6. Control undertaken

6.1 Site selection

A strategic broad-area control program across a range of tenures was instigated as one of the projects basic aims.

Suitable control sites were identified during the mapping phase of the project and were chosen on the basis of ease of access and prioritised according to their position with respect to the top of a catchment.

Other considerations taken into account in site selection included the presence of other environmental management activities such as weed control or restoration plantings. The size of the infestation was also important with site selection focusing on areas that could deliver results in a defined period of work.

A range of tenures were targeted to maximise opportunities for a broad range of landowners and managers to participate in the project and gain skills in weed control techniques, in addition to access to technical support and financial assistance. Permission was obtained from all landowners before any control was undertaken.

Most pond apple control work was undertaken during November and December of 2002. A Memorandum of Understanding (MOU) was drawn up between the Queensland Parks and Wildlife Service (as project coordinator) and respective Councils or community groups providing them with a cash contribution towards costs. Each recipient provided 'in-kind' contributions. The sites chosen in the first round of control activities are described and summarised in **Table 6** below.

Table 6: Sites for the first round of pond apple control – commencing September 2002

Site Description	Cairns City (Dinner Creek tributary) 3 freehold properties and Council Reserve)
Advantages -	Removal of key upstream seed source. Control work starting at top of catchment.
Disadvantages of control at this site	Various land tenures and dense thicket on Dinner Creek Road.
Infestation	Dense thicket at top of catchment.
Ecosystems[♦]	7.8.1 - (1a) of Concern, 7.3.5 -(15a) of Concern, 7.3.3 - (3a) Endangered.
Control objectives	Opportunity to estimate costs for control for a dense, hard to access infestation. Work starting at top of catchment.

♦ Sattler and Williams 1999

Table 6 (cont.): Sites for the first round of pond apple control – commencing September 2002

Site Description	**Cardwell Shire Drainage Reserve Lots 90 RP868968, and 96 RP904399 about 58 ha**
Advantages - **Disadvantages of control at this site**	Council Reserve in process of being revegetated. High possibility of ongoing maintenance. Trees are isolated not a task suitable for a large work crew.
Infestation	Mostly isolated trees with some smaller clumps of younger trees. Isolated intact melaleuca communities linked by narrow disturbed creek banks.
Ecosystems[♦]	7.3.6 - (18) Endangered, 7.3.5 - (15a) Not of Concern.
Control objectives	Opportunity to estimate cost of controlling sparse infestation of differing size trees along creek.
Site Description	**Cairns City - Alice River Lot 1 RP740532**
Advantages - **Disadvantages of control at this site**	To be gazetted as National Park. Links to existing NP with active pond apple control program in place. Reasonable access to site. May need to be extended into freehold properties further up river.
Infestation	Majority cleared for grazing. Edge trees and young thickets.
Ecosystems[♦]	Drains 7.3.10 -(1a) Endangered, 7.3.3 - (3a) Endangered, 7.3.4 - (3b) Endangered, 7.3.5 - -(15a) of Concern, 7.3.11 (13A) Not of Concern.
Control objectives	Opportunity to estimate costs over a range of infestations types (e.g. thickets understorey and edge trees).
Site Description	**Cairns City - Dinner Creek Lot 2 RP740532**
Advantages - **Disadvantages of control at this site**	To be gazetted as National Park. Links to National Park with active pond apple control program in place. Will need to be extended further up river to dinner Creek Road and beyond.
Infestation	Mostly cleared swamp with pockets and strips of vegetation along creek edges. Young pond apple thickets with some larger trees.
Ecosystems[♦]	7.3.1 -(23e) Endangered, 7.3.3 - (3a) Endangered, 7.3.10 -(1a) Endangered, 7.3.5 -(15a) of Concern.
Control objectives	Opportunity to estimate costs over a range of infestations, including thickets understorey and edge trees.
Site Description	**Cairns City - 109 NPW540** and **Russell River Road**
Advantages - **Disadvantages of control at this site**	Easy for follow-up work. Large trees, some revegetation can also be undertaken. Drains on National Park boundary recently cleaned out and large number of pond apple trees removed. Possible reinfestation from lower catchment.
Infestation	Disturbed rainforest, melaleuca forest and some mangroves. Small and mature trees along the drains
Ecosystems	7.3.3 - (3a) Endangered, 7.3.7 - (19) Endangered, 7.3.5 15a) Not of Concern.
Control objectives	Demonstration site allowing determination of costs of controlling infestation within disturbed palm forest. Small area with 3 different types of infestation including: monoculture, understorey and occasional plants.

[♦] Sattler and Williams 1999

Table 6 (cont.): Sites for the first round of pond apple control – commencing September 2002

Site Description	Cardwell Shire - Murray Upper - Lot 46 RP862627
Advantages	Small area with good access. Suitable for trial of differing revegetation techniques.
Disadvantages of control at this site	Private property may not have follow-up work.
Infestation	Melaleuca communities. Smaller trees with much pond apple regeneration.
Ecosystems[♦]	Data not available.
Control objectives	Opportunity to estimate costs and techniques for a lagoon system incorporating a tree planting component.
Site Description	**Johnstone Shire - Liverpool Creek (numerous sites)**
Advantages -	Possibility of entire catchment control with limited opportunities for reinvasion. Will link with revegetation work previously undertaken along creek by Council and River Improvement Trust.
Disadvantages of control at this site	Multiple landholders, some have planted pond apple. Private property may not have follow-up work.
Infestation	Small thickets at top of catchment, isolated trees along creek, heaver infestation near Browns Mountain on lower reaches. Cleared cane land with some isolated pockets and remnant vegetation along creek bank.
Ecosystems[♦]	Data not available.
Control objectives	Complete control of drainage system. Opportunity to estimate costs of control for isolated trees and pockets over the whole catchment.
Site Description	**Johnstone Shire - Diggers Creek (numerous sites)**
Advantages -	Limited opportunities for reinfestation.
Disadvantages of control at this site	Multiple freehold properties Very wet areas.
Infestation	Mostly pure stands of pond apple with occasional trees along drainage lines below Diggers Creek. Occasional plants occur under the remaining forest cover.
Ecosystems[♦]	Cleared farm land with riparian forest along creek banks.
Control objectives	Opportunity to estimate costs for controlling top of catchment.

Additional 'second round' control sites were selected following the completion of additional mapping (refer **Table 7**). Their selection was based on an expansion of the first round control sites while targeting isolated outbreaks where pond apple could be eradicated from a whole catchment or part of a catchment. The focus for this round was on total catchment outcomes and those projects that could be completed by the 31 October 2003.

[♦] Sattler and Williams 1999

Table 7: Sites for the second round of pond apple control – commencing April 2003

Site Description	Cardwell Shire - Cherrin Creek Lots 2 and 3 RP893457, Lot 12 RP904390 and Lot 4 RP904395
Advantages -	Council reserve in the process of being revegetated. High possibility of ongoing maintenance. Systematic pond apple control of catchment.
Disadvantages of control at this site	Private property, may not have follow-up work.
Infestation	Along drainage lines and in cleared areas with small patches of melaleucas linked by narrow disturbed creek banks.
Ecosystems[♦]	7.3.6 - (18) Endangered, some regrowth melaleuca.
Control objectives	Opportunity to estimate cost of controlling sparse infestation of differing size trees along creek.
Site Description	**Cairns City - Nigger Creek Lot 1 RP740532**
Advantages -	Systematic control of catchment. Area recently gazetted as National Park. Control will link with work undertaken at Dinner Creek (first round) and in Eubenangee National Park with active control program in place. Reasonable access.
Disadvantages of control at this site	May need to be extended into freehold properties further up river.
Infestation	Edge trees and young thickets amongst vegetation along creeks, some pond apple trees in drains. Balance cleared for grazing.
Ecosystems[♦]	7.3.10 -(1a) Endangered, 7.3.3 - (3a) Endangered, 7.3.4 - (3b) Endangered, 7.3.5 - (15a) of Concern, 7.3.11 - (13A) Not of Concern.
Control objectives	Opportunity to estimate costs over a range of infestations inc. thickets, understorey and edge trees.
Site Description	**Cairns City - Dinner Creek Lot 2 RP740532**
Advantages of control at this site -	Systematic control of catchment. Recently gazetted as National Park. Links with Eubenangee Swamp National Park with active pond apple control program in place. Links to areas previously treated under this program.
Disadvantages	Limited access.
Infestation	Edge trees and young thickets with some larger trees throughout cleared swamps with pockets and strips of native vegetation along creeks.
Ecosystems[♦]	7.3.1 -(23e) Endangered, 7.3.3 - (3a) Endangered, 7.3.10 -(1a) Endangered, 7.3.5 -(15a) of Concern.
Control objectives	Opportunity to estimate costs over a range of infestation types inc. thickets understorey and edge trees. Treatment included the felling of timber as well as stem injection of trees missed or not killed in first treatment.

♦ Sattler and Williams 1999

Table 7 (cont): Sites for the second round of pond apple control – commencing April 2003

Site Description	Johnstone Shire - North Maria Creek (numerous sites)
Advantages -	Possibility for entire catchment control. Limited opportunities for reinvasion. Use of Johnston Shire and QPWS staff skilled in pond apple control.
Disadvantages of control at this site	Multiple landholders. Private property, may not have follow-up work.
Infestation	Small thickets in regrowth at top of catchment. Isolated trees along creek, heavier infestations lower down the catchment. Mostly cleared cane land through centre, National Park at bottom of catchment.
Ecosystems[♦]	7.1.1 -(2a) Not of Concern; 7.3.5 -(15a) Of concern; 7.3.6 - (18) Endangered; 7.3.4 - (3b) Endangered; 7.3.10 - (1a) Endangered; 7.3.22 - (1c) Endangered; 7.12.1 - (2a) Not of Concern; and regrowth.
Control objectives	Opportunity to estimate costs over a range of infestations including. thickets understorey and edge trees. Systematic control of catchment. Surplus funds to cover follow-up work on Liverpool Creek.
Site Description	**Cairns City - Mulgrave River (Henning Creek) Lot 6 RP893111 Lot 9 RP893110**
Advantages -	Top of Mulgrave River catchment. Small area. Community involvement.
Disadvantages of control at this site	Possibility of no follow-up by landholder.
Infestation	Understorey of pond apple trees along creek.
Ecosystems	Data not available.
Control objectives	Community involvement. Systematic control of catchment.
Site Description	**Douglas Shire - Daintree National Park Lot 20 NPW695**
Advantages -	Data collection in inaccessible areas. Able to survey a large area.
Disadvantages of control at this site	Large areas of swamp, crocodiles.
Infestation	Mostly coastal swamps, mangroves and woodlands.
Ecosystems[♦]	Various.
Control objectives	Opportunity to estimate costs for aerial investigations of Baileys Creek and Daintree areas using helicopter.

♦ Sattler and Williams 1999

6.2 Work force

The project aimed to develop a workforce skilled in pond apple control across a range of government and non-government landholder groups. As most of the control work was carried out under hazardous physical conditions it is recommended that only trained and experienced staff be used for pond apple control. Natural hazards such as the presence of crocodiles in swamps, creeks and riverbanks needs to be taken into consideration at all times.

Teams employed to participate in different parts of the control program included:

- A group from *Conservation Volunteers Australia* who were trained and engaged for two weeks work at Dinner Creek. They worked well through some of the hottest days in 2002. However, due to their lack of experience in weed control they were not competent in the more skill requiring treatment of large pond apple trees. Their skill and experience levels were adequate for the effective treatment of areas containing smaller trees and seedlings.
- Cardwell and Johnstone Shire staff were utilised for control work within their Shires under agreements outlined in MOUs. Council staff were used where possible to assist in the merging of pond apple control into their on-going weed management programs and to increase their skill levels. They were also provided with specialist equipment. In council areas ongoing follow-up treatment will be the responsibility of shire staff.
- QPWS staff were engaged on National Parks and in other areas. Staff based at Josephine Falls and Innisfail have been active in pond apple control over many years, particularly within Eubenangee Swamp National Park. QPWS staff are experienced in control work and have ready access to equipment. This project enabled them to target areas that would otherwise be outside their core activities and to further refine their control techniques.
- Mulgrave Landcare and Catchment group who are actively replanting creeks, drains and riverbanks with native species to prevent erosion and weed invasion. They are working with the River Improvement Trust in the Mulgrave River catchment and are actively removing pond apple and rehabilitating treated areas through the planting of native species.

6.3 Cost of control

Detailed records of hours, materials, techniques and areas covered were kept throughout the duration of the project. These records were used to calculate the costs of completed work and for the estimation of the costs, time, materials and personnel required for follow-up treatments.

The highest cost during the project was $20,690 per hectare for a dense pond apple infestation, while the lowest cost was $140 per hectare for a sparsely infested area (both areas had trees of approx approximately 5cm diameter). Overall, the average cost of treatment per hectare was $2 860. **Tables 8 and 9** summarise the costs of treating different infestation types and the costs of different control techniques.

Table 8: Cost estimates for different infestation types

Infestation Type	Control cost ($ per ha)		
	Average Cost	**Maximum cost**	**Minimum Cost**
Drain	$7 800	$20 690	$1 720
Edge	$9 770	N/A	N/A
Regrowth	$1 750	$4 940	$140
Thicket	$4 510	$1 4960	$560
Understorey	$1 450	$4 530	$450

Table 9: Cost estimates for different control techniques

Control Type	Control cost ($ per ha)		
	Average Cost	**Maximum cost**	**Minimum Cost**
Cut Stump	$2 750	$20 690	$170
Foliar	$3 170	$4 940	$170
Heavy Plant	$14 960	N/A	N/A
Hand Pull	$1 310	$3 610	$170
Stem injection	$2 660	$7 970	$140

Based on these cost estimates the funding required for pond apple control in different catchments within the Wet Tropics bioregion were calculated (refer **Table 10)**, along with costs already expended under this project. The costs calculated are for a single treatment and do not include follow-up work.

Table 10: Costs for pond apple control for different catchments and shires (based on average costs for a single treatment)

Shire	Catchment	Area to be controlled (ha)	Cost of initial treatment
Mareeba	Barron River	32	$30 165
	Davies Creek	1	$1 647
Total		**33**	**$31 812**
Douglas	Baileys Creek	264	$342 938
	Daintree River	28	$115 287
	Mossman River	20	$6 750
Total		**312**	**$464 975**
Cairns City	Canal/Alice River	941	$1 605 286
	Mulgrave River	26	$67 857
	Norries Creek	3	$13 303
	Russell River	69	$194 150
	Trinity Inlet	39	$63 699
Total		**1078**	**$1 944 295**

Table 10 (cont): Costs for pond apple control for different catchments and shires (based on average costs for a single treatment)

Johnstone	Big Maria Creek	25	$35 070
	Ella Bay	3	$5 789
	Liverpool Creek	11	$26 535
	Mission Beach	20	$58 687
	Moresby Creek	34	$111 368
	Ninds Creek	125	$477 078
	North Johnstone River	28	$121 132
	North Maria Creek	33	$24 662
	Stone Creek	3	$19 865
	South Johnstone River	90	$167 544
	South Maria Creek	8	$10 016
	Victory Creek	10	$48 673
Total		**390**	**$1 106 419**
Cardwell	Murray River	235	$301 734
	Tully River	2	$3 735
Total		**237**	**$305 469**

Using the average costs for differing infestation types, the cost to undertake the initial control of the entire Wet Tropics bioregion is estimated to be **$3,852,970**.

The costs involved in undertaking follow-up control for at least two years after the eradication of the last seedlings need to be factored in any detailed project proposal.

7. Education and community awareness

A number of landholders were unaware of pond apple or that it was present on their property as it generally grows in infrequently visited areas. Some were not aware of pond apple's potential for major economic or environmental harm.

Liaison and information sharing was an integral part of the project and was particularly effective with staff from the Douglas, Johnstone and Cardwell Shires and from Cairns City Council. Liaison was ongoing with QPWS across the region especially with the skilled, experienced and well-equipped staff from Josephine Falls and Innisfail.

Assistance was provided to the Mulgrave Landcare and Catchment Group through the provision of equipment for herbicide stem injection, chemicals and technical information and advice. A media campaign was organised to coincide with pond apple control at Hemming Creek.

Technical assistance was offered to the Johnstone River Landcare Group. However, their time was already committed in other areas. Some support was provided to the Group in the form of information and local area maps showing pond apple infestations.

Technical information and herbicide was provided to landholders in the Murray River catchment actively engaged in controlling pond apple on their properties.

Awareness of the need for pond apple control and the project were further promoted through several initiatives including:

- Introduction of project at the **Innisfail subdistrict meeting of QPWS** (July 2002).
- Introduction of project to **Mulgrave Land Care Group** (September 2002).
- Article in the **Wet Tropics Management Authority's Neighbours Newsletter** (September 2002).
- Article in the **NQ Landcare Community Update** (October 2002).
- Presentation to the **Wet Topics Community Consultative Committee** (November 2002).
- Presentation to the **Far North Queensland Pest Advisory Forum** in Atherton (December 2002).
- Article in the **QPWS Environment Management Unit publication** and in the QPWS **Wild Times** newsletter (February 2003).
- Presentation of Maps showing areas susceptible to pond apple invasion to **Far North Queensland Pest Advisory Forum** in Herberton (March 2003).
- **Win TV** news story "Working with local landcare group to control pond apple within the catchment" (August 2003)**.**
- **Cairns Post** article "Impacts of pond apple within Wet Tropics and details of current control program" (August 2003).
- **Caring For Country Course, TAFE College** field day outlining pond apple problems and techniques for control for (August 2003).
- Interviews with Mulgrave Landcare Co-ordinator on 2 local radio stations, **ABC** and **4KZ** re impacts of pond apple within the Wet Tropics (August 2003).
- Presentation of results of project to **Far North Queensland Pest Advisory Forum** in Malanda (June 2004).

Although one of the aims of this project was to produce a best practice booklet on various pond apple control techniques, this was not possible within project timelines. However, this report will be distributed to councils, QPWS, Landcare agencies, Land Protection Officers, and the Natural Resource Management Board in the Wet Tropics bioregion.

The report will also be made available on the Wet Tropics Management Authority's website: (http://www.wettropics.gov.au/mwha/mwha_weeds.html).

8. Project budget

The total costs of this project were $419,950 comprising a cash contribution of $213,700 provided by the Natural Heritage Trust through the Weeds of National Significance program and in-kind contributions of $206,250.

Of the Natural Heritage Trust funding, $164,000 was allocated for employment and $49,700 for operating expenses. Contractor's costs shown included wages and operating expenses. A breakdown of project costs is shown in **Table 11** and in-kind contributions in **Table 12.**

Table 11: Breakdown of NHT funds

Description	2002/3	2003/04	Total
Wages	$54 027	$65 491	$119 518
Operating expenses	$376	$587	$963
Vehicles	$1 500	$4 688	$6 188
Contractors[4]	$16 269	$49 700	$65 969
Office/printing	$130	$4 258	$4 388
Safety equipment	$655	$1 179	$1 834
Herbicides	$3 035	$7 763	$10 798
Fuels	$22	$2 217	$2 239
Control Equipment	$2 007	$2 332	$4 339
Total NHT Funds	**$78 021**	**$13 8215**	**$216 236**

Table 12: Breakdown of in-kind contributions

Participants	Description of contribution	In-kind
WTMA	Prepare project application, provide administrative, GIS, technical support, scientific evaluation and media liaison. Prepare and distribute report.	$47,500
QPWS	Employ coordinator; provide assistance with identification of areas of infestation and liaison with landowners; vehicles and labour for establishment of control areas and use of GIS	$108,750
Cairns City Council	Assistance with on ground control work	$1,500
Cardwell Shire Council	Assistance with on ground control work	$1,500
Johnstone Shire Council	Assistance with on ground control work	$1,500
Douglas Shire Council	Assistance with on ground control work	$4,500
DNRME	Provide scientific and technical assistance. Assist in education and awareness programs	$29,000
Mulgrave Landcare Catchment Group	Liaison with landowners and community education. Revegetation of controlled areas and those identified in predictive mapping as suitable for possible future infestation.	$10,000
DPI	Local knowledge, extension to farmers	$2,250
Total In-kind Funds		**$206,250**

[4] Payment to Councils for control work include wages, herbicide and equipment

9. Recommendations

9.1 Further control

High priority areas suggested for future control work are the upper parts of the catchments listed below in **Table 13**.

Table 13: Priority catchments for future control work

Catchment	Estimated Cost
Daintree River	$115 287
Norries Creek	$13 303
Victory Creek	$48 673
Stone Creek	$19 865
Moresby Creek	$111 387
Big Maria Creek	$24 662
South Maria Creek	$10 016
Mission Beach	$58 687
Tully River	$3 735
Murray River	$301 374

It is recommended that the planning and eradication of pond apple in the Wet tropics bioregion should be conducted using the following approach:

- Prioritise areas for control based on the size of infestations and the level of resources required to complete the project. Large projects requiring work to be conducted over several years should be sub-divided into smaller areas and treatment scheduled to avoid fresh seed being transported into previously controlled areas. This can be done by targeting streams in one year, the flood plain the following year and tidal areas subsequently. The removal of upstream seed sources greatly reduces the need for follow-up treatments.

- Undertake follow-up treatments no later than two years after the initial control and continue until two years after the last tree is killed. This will ensure that all viable seed in an area is exhausted.

- Ensure adequate funding and resourcing is available to achieve eradication. Recurrent funding must be available for a minimum of two years after any final major control project to cover the cost any follow-up treatments which might be required until the existing seed bank is exhausted.

9.2 Recommended future research

- *Mapping, modelling and field surveys*
  Additional ground surveys are required to verify and improve the accuracy of the predictive mapping. At the time of the initial data collection, updated vegetation mapping was unavailable for the northern and southern sections of the project area. This updated vegetation mapping has since been completed and additional predictive mapping to a higher degree of accuracy is now possible.

- *Disturbance*
  It is not known what constitutes the minimum amount of disturbance required within different native vegetation communities for pond apple to

become invasive. Further research is also required to investigate what triggers invasions in different parts of a catchment, in different landform elements and in different vegetation community types.

- *Water dispersal of seed*
  Further to the point above, investigations into the relationship between seed dispersal, the pattern of invasion and specific flood/cyclone events.

- *Animal dispersal of seed*
  Investigate possible relationships between patterns of seed dispersal (especially isolated outbreaks) and the transport of pond apple seed by animals such as flying foxes, cassowaries, other birds and pigs.

9.3 Community awareness and education

Ongoing pond apple education and extension programs are needed targeting landholders, state and local government officers and Landcare agencies.

It is recommended that a communication program, targeting landholders in the Wet Tropics bioregion, be implemented to promote awareness about material available on the identification and control of pond apple on the Department of Environment and Heritage ‘s website:

- http://www.deh.gov.au/biodiversity/invasive/weeds/pubs/a-glabra.pdf

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Pier (Pacific Island Ecosystems at Risk) *Institute of Pacific Islands Forestry* 2003

Appendix 1

Table A1: GPS code descriptions

Code	Primary Infestation Type	Secondary Infestation Description
B	Beach	Plants grown from ocean-transported seed
C	Controlled	Areas that have been controlled in the past
D	Drainage line	Rivers, creeks and drains where pond apple is dominant
F	Fence line	Occasional trees found along fence lines, seed deposited by water flow or from bird droppings in hilly areas
I	Individual	Single trees isolated from other trees
M	Mature tree	Mature trees occurring in isolation from denser, younger infestations. These trees could have been missed during previous control. They are significant as possible sources of new infestations
P	Project control area	Areas controlled under this project
R	Regrowth	Smaller trees that are not yet producing fruit
T	Thicket	Dense stands of pond apple (where more than 50% of the trees are pond apple)
U	Understorey	Infestations occurring under mature trees of another species (pond apple is not the dominant species)

Table A2: Codes used in shape file tables to describe polygons

Code	Description
Id	A unique number for each polygon.
Code	The main GPS descriptive code (refer **Table A1**)
Code2	The secondary descriptive code (refer **Table A1**)
Source	The source of information and an indicator of the likely accuracy of that information (described in brackets)
C	Council Staff (good)
E	Extrapolated information based on such factors as expected seed movement (poor)
G	GPS (excellent)
Q	QPWS staff (good)
R	Research Staff (good)
V	Visual observation (very good)
DSC	Douglas Shire
CCC	Cairns City area
JSC	Johnstone Shire
CSC	Cardwell Shire
MSC	Mareeba Shire
Catchment	This describes the catchment the polygon is within. The catchment areas are based on the most logical areas for control work (refer **Map 2**)
Area	The area of the polygon in square metres
Control **C** **L** **NP** **P**	Describes who has performed control work within the area of the polygon: Council Landholder QPWS staff Work performed under this project

Table A3: Codes used to describe individual control site polygons

Code	Description
Id	A unique number for each polygon.
Code	The main GPS descriptive code (refer **Table A1**)
Area	The area of the polygon in metres^2
Date	Date work was done
Workforce	Who undertook the control work
DSC	Douglas Shire
CCC	Cairns City area
JSC	Johnstone Shire
CSC	Cardwell Shire
MSC	Mareeba Shire
QPWS	Queensland Parks and Wildlife Service
CVA	Conservation Volunteers Australia

Appendix 2

Table of rivers and creeks infested with pond apple in the Wet Tropics Bioregion: sorted by Shire

Douglas Shire			
Creek	**Catchment**	**Infestation**	**Control Undertaken**
Bailey Creek, incl. Hutchinson & Buchanan Creeks	Bailey/Cooper Creeks	Understorey through most of the area including mangroves	Council some QPWS
Mackenzie Creek	Bailey/Cooper Creeks	Small clumps in drains, some isolated trees	Council
Tributary of Mackenzie Ck	Bailey/Cooper Creeks	Thickets and dense infestation along water courses	Council
McLean Creek	Bailey/Coopers Creeks	Isolated trees, becoming thicker at bottom of catchment	Nil
Lutta Creek	Daintree River	Isolated trees with some thickets developing	Nil
Forest Creek	Daintree River	Not inspected	Nil
Daintree River	Daintree River	Isolated trees along drains, thicket developing at mouth of Daintree River	Council
Barrett Creek	Daintree River	Isolated trees occurring as understorey in Melaleuca forests	Council
Marr Creek	Mossman River	Scattered infestations turning to isolated trees on lower reaches	Council
Mossman River	Mossman River	Isolated trees	Council
Mareeba Shire			
Paddy Creek	Davies Creek	Understorey trees	Controlled under this project
Jumrum Creek	Barron River	Understorey plants growing along creek	Controlled by Council
Barron River (Kamerunga)	Barron River	Some individual large trees	Council controlled in 1999: requires follow up
Cairns City			
Skeleton Creek	Trinity Inlet	Understorey of trees in creek west of Bruce Highway in areas adjacent to council park	Previously controlled by Council, some missed trees re-establishing
Firewood Creek	Trinity Inlet	Young infestation	Control work started under this project
Wrights Creek	Trinity Inlet	Some individual large trees	Council controlled in 1999: requires follow up
Hemming Creek	Mulgrave River	Isolated trees along creek to north of flood plain amongst revegetation	Control undertaken within this project
Mulgrave River	Mulgrave River	Thickets where swampy and scattered trees along banks	Nil - landholder anxious to participate
Russell River	Russell River	Thickets where swampy and scattered trees along banks, un-maintained cleared areas have dense infestations, some drains infested	Nil, some land holder participation
Norries Creek	Russell River	Thickets where swampy and scattered trees along banks	Control required upstream to prevent reinfestation lower down catchment

Cairns City continued			
Creek	**Catchment**	**Infestation**	**Control Undertaken**
Canal Creek	Canal/Alice River Eubenangee	Occasional trees in mid reaches	Control undertaken within this project
Nigger Creek	Canal/Alice River Eubenangee	Thickets where swampy, occasional trees along Creek	Control undertaken within this project
Dinner Creek	Canal/Alice River Eubenangee	Thickets where swampy, occasional trees along river	Control undertaken within this project
Bramston Beach	Bramston Coastal	Seed in creek no trees found. Infestation in farmland	Nil
Johnstone Shire			
Polly Creek	North Johnstone River	Occasional trees thickets in damper areas	Nil
Catelan Creek	North Johnstone River	Dense thickets along creek and drains	Nil
Sandfly Creek	North Johnstone River	Some thickets and understorey trees	Some work adjacent to revegetation
Stone Creek	Stone Creek	Occasional trees extending along creek	Nil
Sweeney Creek	South Johnstone River	Overflow from town swamp, dense thickets	Nil, some control (no follow up)
Saltwater Creek	North Johnstone River	Pond apple along creek Overflow from town swamp.	Nil
South Johnstone River	South Johnstone River	Occasional trees on riverbank	Nil
Bamboo Creek	South Johnstone River	Occasional trees along Creek. Thicker where no remnant trees, dense in swamps.	Nil
Swampy Creek	South Johnstone River	Dense on headwaters extending to Bamboo Ck in rainforest. Some thickets developing in swampy grazing areas and wider parts of creek	Nil
Zahra Creek	South Johnstone River	Monoculture along creeks, and dense understorey in swamps	Nil
Junction Creek	South Johnstone River	Occasional trees along Creek thicker where no remnant trees and dense in swamps	Nil
Ninds Creek	Johnstone River	Dense in cleared unmanaged areas. Invading melaleuca communities and edges of remnant vegetation. Prolific along drains.	Small amount within Innisfail town area
Daru Creek	Moresby River	Some pest trees at head of creek, plants known in lower reaches which drains into Moresby River wetlands	Nil
Boobah Creek	Moresby River	Occasional trees along creek. Cane drains infested, plants known in lower reaches which drains into Moresby River wetlands	Nil

Johnstone Shire continued			
Creek	**Catchment**	**Infestation**	**Control Undertaken**
Liverpool Creek	Liverpool Creek adjoins Tully catchment	Small infestation around Brown Mt Thickets at top of catchment, isolated trees along remainder	Controlled under this project
Pandanus gully	North Maria Creek	Occasional trees along creek bank	Controlled under this project
North Maria Creek	Big Maria Creek	Small thickets at top of catchment, isolated trees along creek with heavier infestations down stream	Controlled under this project
Big Maria Creek	Big Maria Creek	Relatively new infestation, isolated trees along creek with heavier infestations down stream	Nil
Rees Creek	Ella Bay Coastal	Trees in clumps and forming edge along creek	Nil
Cooper Creek	Ella Bay Coastal	Stunted trees and seedlings at creek mouth	Nil
Midgee Bar Creek	Mission Beach Coastal	Trees occasionally along creek bank lower part of catchment	Nil
Muff Creek	Mission Beach Coastal	Trees occasionally along creek bank lower part of catchment. Some areas of thickets developing on edges of melaleuca forest	Nil
Cedar Creek	Mission Beach Coastal	Trees occasionally along creek bank, reported on dam on banana plantation	Nil
Wylies Creek	Mission Beach Coastal	Tree noted near bridge 10m from ocean	Nil
James Creek	Mission Beach Coastal	Trees at mouth of creek	Nil
Cardwell Shire			
Michael Creek	Murray River	Occasional plants along drains, occasional understorey in melaleuca swamps	Landholder
Cherrin Creek	Murray River	Occasional plants amongst riparian vegetation on grazed country	Controlled by Council under this project
Warrami creek	Murray River	Occasional plants under well developed melaleuca forest	Controlled by Council under this project
Murray River	Murray River	Infestation limited to mid reaches of the river on flood plains, some trees in drains killed by landholders Previously recorded thickets cleared for cane land	Landholder control with help from this project
Henry Creek	Murray River	Understorey plants growing in seasonally dry creek bed	Nil
Porter Creek	Murray River	Occasional trees along vegetated creek bank	Landholder control with help from this project
Leverdale Creek	Murray River	Occasional trees along vegetated creek bank	Nil

Note: Only named creeks have been listed