Assessment of research needs for the management of invasive species in the terrestrial and aquatic ecosystems of the Wet Tropics

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Contents

List of Figures

List of Tables

Abbreviations Used In This Report

pers. comm. ..... personal comment
pers. obs. .... personal observation
unpubl. .... unpublished

Acronyms Used In This Report

ACTFR .... Australian Centre for Tropical Freshwater Research
AFHR .... Australian Fisheries Habitat Review
AHP................... Analytical hierarchical process
ANU................... Australian National University
AQIS.................. Australian Quarantine Inspection Service
ARC................... Aboriginal Rainforest Council
ARF .... Australian Rainforest Foundation
ARIER .... Arthur Rylah Institute for Environmental Research
AWC.................. Australian Weeds Committee
BCA................... Benefit-cost analysis
BRS................... Bureau of Rural Sciences
CCC................... Cairns City Council
CDCP .... Centre for Disease Control and Prevention
CRC................... Cooperative Research Centre
CERF................. Commonwealth Environment Research Facilities
C of A................ Commonwealth of Australia
CSIRO .... Commonwealth Scientific and Industrial Research Organisation
DAFF................. Commonwealth Department of Agriculture, Fisheries and Forestry
DEH................... Commonwealth Department of the Environment and Heritage, now Commonwealth Department of Environment and Water Resources (DEWR)
DEWR .... Commonwealth Department of the Environment and Water Resources
DNRME .... Queensland Department of Natural Resources, Mines and Energy, now Queensland Department of Natural Resources and Water (DNRW)
DNRM................ Queensland Department of Natural Resources and Mines, now DNRW
DNRMW .... Queensland Department of Natural Resources, Mines and Water, now DNRW
DNRW .... Queensland Department of Natural Resources and Water
DSS................... Decision Support Systems
DPIF .... Queensland Department of Primary Industries and Fisheries
EA .... Environment Australia
EAEP................. Electric Ant Eradication Program
EPA................... Queensland Environment Protection Agency
EPBC .... Environment Protection and Biodiversity Act 1999
FNQNRM........... Far North Queensland Natural Resource Management
FNQLGPPAC.... Far North Queensland Local Government Pest Plan Advisory Committee
FNQROC........... Far North Queensland Regional Organisation of Councils
GBR .... Great Barrier Reef
IACRC .... Invasive Animals Cooperative Research Centre
IBRA.................. Interim Biogeographic Regionalisation for Australia

IUCN.................. World Conservation Union
JCU .... James Cook University
LGA................... Local Government Area
LGAPMP .... Local Government Area Pest Management Plan
MODSS .... Multiple Objective Decision Support System
MoU................... Memorandum of Understanding
MTSRF .... Marine and Tropical Sciences Research Facility
NAQS .... North Australian Quarantine Strategy
NEWAL .... National Environmental Weeds Alert List
NFACP .... National Feral Animal Control Program
NFAEP .... National Fire Ant Eradication Program
NHT .... National Heritage Trust
NQTF................. North Queensland Threatened Frog
NQTFRT............ North Queensland Threatened Frog Recovery Team
NSWDECC........ New South Wales Department of Environment and Conservation
NWS .... National Weeds Strategy
PAC CRC .... Pest Animal Control Cooperative Research Centre
PMP................... Pest Management Plan
PNG................... Papua New Guinea
QFPMS.............. Queensland Feral Pig Management Strategy
QPAS .... Queensland Pest Animal Strategy
QPWS .... Queensland Parks and Wildlife Service
RA .... Risk Assessment
RCD................... Rabbit Calici Disease
RPMP .... Regional Pest Management Plan
RRRC .... Reef and Rainforest Research Centre Limited
RSPCA.............. Royal Society for the Prevention of Cruelty to Animals
SC .... Shire Council
SWEEP .... Strategic Weed Eradication and Education Program
TAP .... Threat Abatement Plan
UQ..................... University of Queensland
USGS .... Untied States Geological Survey
USQ................... University of Southern Queensland
VPC .... Vertebrate Pest Control
WNV .... West Nile Virus
WoNS................ Weeds of National Significance
WRA.................. Weed Risk Assessment
WTCS................ Wet Tropics Conservation Strategy
WTMA .... Wet Tropics Management Authority
WTVPRAS .... Wet Tropics Vertebrate Pest Risk Assessment Scheme
WTWHA .... Wet Tropics World Heritage Area
WTR .... Wet Tropics Region
4TWP .... Four Tropical Weeds Program

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Executive Summary

This report is a synthesis of past and current research and management of invasive species in terrestrial and freshwater ecosystems of the Wet Tropics bioregion. Its intention is to identify knowledge gaps and critical needs and thus recommend future opportunities for investment in research and management of invasive species in the Wet Tropics bioregion. The report includes previous and current priority listings of invasive species of concern, developed on behalf of stakeholders and researchers. It reviews the outcomes of actions taken to address these invasive species and evaluates the impacts and capacity to meet these and future threats. This information has been synthesised from a series of workshops and face-to-face meetings with stakeholders, and a review of the primary and secondary literature.

The proposed MTSRF study areas contain the terrestrial and freshwater ecosystems occurring within the following legislative regions: Wet Tropics bioregion, the Far North Queensland Natural Resource Management boundary, the Wet Tropics World Heritage Area, and a southerly extension to incorporate the rainforest area of Mt Elliot, regarded as a southern outlier of the Wet Tropics bioregion on floristic and faunistic grounds. Within the MTSRF Rainforest Projects the combined areal extent of these regions is extended by a twenty kilometre buffer to minimise edge effects in the modelling of environmental conditions and species distributions.

Invasive Species of Concern in the Wet Tropics Region

Terrestrial Vertebrates

The main terrestrial vertebrate pests in the Wet Tropics Region (WTR) are all well established and have been identified as the feral pig, cat, cane toad and wild dog/dingo (Harrison and Congdon 2002). Despite many attempts to control feral pigs and research into their ecology, they remain a major pest, causing significant damage to the environment and they are potential carriers of disease such as Japanese encephalitis. Research by Hudson (2005) has identified feral deer as an emerging significant threat to the region. As they are in the early stages of invasion, there is the possibility that they can be controlled whilst still at low population densities. Relatively little research has been undertaken into quantifying the environmental impacts of the other main vertebrate species in the WTR and this is urgently required to determine their actual pest status.

Terrestrial Weeds

There are now over five hundred exotic plant species that have become naturalised in the WTR (Queensland Herbarium, cited in Werren 2001), nine of which are on the Weeds of National Significance (WoNS) list (Williams and West 2000). Weed management in the WTR is focused on those weed species where successful control can be achieved, particularly weeds with the potential to invade ecosystems that are currently intact. Of major concern are those species that could change ecosystem processes within WTR rainforests. These include garden escapes, exotic species that have become naturalised and native species now growing beyond their natural ranges. Sleeper species that are present in the WTR but are not yet having a significant impact and the introduction, intentional or accidental, of new weed species are major threats in the future.

Aquatic Weeds

Seven aquatic weed species were identified by Werren (2001) as being of high risk to the waterways of the WTR, however of these, three do not appear to be having a significant impact at present. The remainder, water hyacinth (*Eichhornia crassipes*), water lettuce

(*Pistia stratiotes*), salvinia (*Salvinia molesta*), and cabomba (*Cabomba caroliniana*) all grow rapidly, reproduce vegetatively and form dense floating mats of vegetation which choke waterways, shade out native vegetation, lower water quality and cause aquatic biota to die from lack of dissolved oxygen. Salvinia and cabomba are both Weeds of National Significance and are being managed as part of the national control strategies. All of these plants were intentional introductions to ornamental ponds and have since escaped into surrounding waterways.

Aquatic Vertebrates

The two tilapia species (*Oreochromis mossambicus* and *Tilapia mariae*) pose the greatest immediate threat to WTR freshwater fish and aquatic ecosystems as they rapidly spread throughout the waterways. Their large body mass and tolerance of a wide range of environmental conditions enables them to dominate and exclude most native fish species. Native fish that have been translocated beyond their natural range and exotic and ornamental fishes that have been released are also a major threat to native fish diversity. Most of the latter have been deliberately introduced and social and cultural attitudes toward these fish species and the human role in the dispersal of these fishes is a major issue. Further introductions of fishes along with the arrival of new aquatic diseases and the lack of effective species-specific controls are regarded as future threats.

Invertebrates

Whilst much is known about invertebrate pests that cause damage to horticultural crops and production industries, relatively little is known of invertebrate pests in the WTR that may cause environmental damage. Two species of tramp ants have been detected and contained within the WTR in the past seven years. Based on overseas experience, both these species have the potential to affect native biota and social amenity. Exotic earthworms have the capacity to change ecosystem processes, soil nutrient availability and species composition within rainforests, yet virtually nothing is known about their ecological impacts in the WTR.

Disease

Two soil-borne pathogens (*Phytophthora cinnamomi* and *Batrachochytrium dendrobatidis*) have caused significant mortality of woody plants and amphibians, respectively, during the initial stages of their invasion in areas of the WTR, and they continue to be the focus of research and management. Recent studies have indicated that some parts of the rainforest are able to recover after infection and at least one species of rainforest frog has also recovered to pre-infection levels. The potential arrival of mosquito-borne diseases such as West Nile Virus and the potential arrival of avian bird influenza are serious threats to the region. Avian malaria which has had devastating effects on endemic birds in Hawaii is present in Australia but its impact in the WTR is unknown.

Capacity to Deal with These Threats

The capacity to deal with current and future threats from invasive species in the WTR is variable. Although much effort has been expended on controlling feral pigs, they remain in large numbers throughout the WTR and control is limited to localised areas. The capacity to deal with feral deer in the WTR is sufficient to be successful if early action is taken, but this is complicated by confusion over whose responsibility it is to do so and inconsistent legislation. Weed management in the WTR has been successful for weeds that are in the early stages of invasion, but for those that have been established for a long time, control at a manageable level and the prevention of spread to new areas, rather than total eradication, is the only option. Capacity to deal with the two tramp ant species that have been detected in the WTR already has been sufficient, but lack of knowledge of other invertebrate pests means that preparedness for other outbreaks is limited. Knowledge about the dynamics of *P. cinnamomi* and *B. dendrobatidis* is still being gathered and in the meantime, precautionary hygiene protocols have been implemented but are yet to be evaluated for effectiveness.

In all of the invasive species issues, regular surveillance and monitoring, improved risk assessments, consistent legislation and enforcement of laws appear to be the main methods of prevention of further invasive species introductions. Knowledge of species that are known pests overseas in similar environmental conditions and how they can be controlled will contribute to some extent to preparedness here. Early detection and early action are regarded as the most efficient courses of action when possible. The next steps include prevention of spread, eradication or control, understanding the invasion process (research), containment and extension work. In many instances, understanding the cultural and social attitudes towards invasive species and raising awareness of the seriousness of invasive species problems is crucial to managing the problem. Community participation is also an important part in the early detection, surveillance and control of invasive species.

Strategies and Research Needs for Invasive Species

As with any question about a complex phenomenon there are multiple levels and ways in which research into invasive species management might be approached. Two broad research approaches can be identified: tactical and strategic approaches. Once an invasive has moved well into the spread phase it is only through a combination of effective control methods applied in a strategic manner that will ultimately result in successful control. It is fair to say that most research and management effort relevant to the WTR has focused at the tactical end of the scale and that this is the research area where resources are most easily obtained. Strategic approaches, which are key to the successful deployment of tactical approaches and ultimately to the successful control of spreading invasives, are less well investigated and resourced. Successful, strategic approaches to control need to incorporate an understanding of population dynamics and spread and be implemented in a manner in which these are managed at a variety of spatial scales. In addition, because control of invasive species can be both an economic and ethically charged issue, and because many invasives achieve a great deal of their spread through human agency, an understanding of the socio-economic context and influence on management approaches needs to be explicitly considered in many cases. Ideally, these socio-economic considerations should be incorporated, through modelling tools, into management planning. Thus, the management of inasive species is a very complex problem with multiple factors and scales. This is an unenviable position and one in which research can provide assistance in the form of decision support systems (DSS) that allow managers to make their decisions in the context of established frameworks that incorporate existing knowledge of the system and processes underlying the issues.

Decision support systems can be developed and applied for implementation in all stages of the management of biological invasions, from frameworks to assist in identifying the types of species that should be stopped prior to introduction, to determining the appropriate management effort required to achieve a desired level of control. They can also be used to predict the relative 'value' outcomes of different courses of action, and this is one area of research that is being actively pursued outside the Wet Tropics. There would be value in collaborating with researchers on these methods using Wet Tropics case studies. Models also need to be ground-truthed and adjusted to real world conditions. A collaborative project with the Decision Theory CERF hub, using Wet Tropics invasive species, setting priorities through formal decision analysis, modelling likely outcomes of control scenarios, adjusting models in light of on-ground experience and monitoring performance indicators, is something that should be considered. While such tools do not make decisions for managers, they assist managers by identifying likely outcomes of particular actions. In both workshops and discussions with managers during the preparation of this report, the development of DSS for application in the WTR was consistently expressed as a pressing need.

For DSS to work effectively they must reflect the conditions in which they are being applied. Given the uniqueness of WTR ecosystems this means that for many aspects of invasive species control specific DSS tools will need to be developed from scratch or existing DSS tools will need to be significantly modified to adequately reflect the processes underpinning invasion in complex tropical ecosystems. In many instances, however, the basic data required is unavailable for the WTR context. Thus, a clear research need is an improved understanding of invasion processes in tropical systems. It needs also to be remembered that invasions are processes involving people and that an understanding of the social and economic context and processes are also important in the development of DSS tools for some types of invasion or aspects of the management of invasive species.

Thus a major research need is a predictive understanding of invasions in tropical ecosystems as a process:

- Of single species spread through landscapes.
- Of species interactions in complex communities.
- Under human social and economic influence.

Given the taxonomic and functional diversity of current and future invasive threats to the WTR this cannot be done in the context of a single type of invasion but will have to be repeated for the major invasives groups, e.g. woody plants, fish, etc. Such information forms the basis not just of an understanding of invasions but also of DSS that can be utilised in successfully combatting them.

In addition to these more general research needs, Table 17 summarises the research needs for specific species and types of invasives.

Introduction

This report synthesises past and current research and management of invasive species in terrestrial and freshwater ecosystems of the Wet Tropics bioregion with the intention of ensuring that current and future investments in invasive species research made through MTSRF and RRRC are focused for greatest effect. It includes previous and current priority listings of invasive species of concern, developed on behalf of stakeholders and researchers. It reviews the outcomes of actions taken to address these invasive species and evaluates the impacts and capacity to meet these and future threats. This information is synthesised in order to identify knowledge gaps and critical needs and thus recommend future opportunities for investment in research and management of invasive species in the Wet Tropics bioregion.

Methodology

Invasive species management and research is a rapidly moving topic, in which the situation of yesterday can potentially be forgotten as a new incursion or the application of a new control method changes perceptions and needs on the ground. Consequently, any assessment of research needs cannot rely solely on the published literature or reports from government agencies, the knowledge and experience of the people on the ground today needs also to be incorporated. Thus, to ensure that as many sources of information as possible were incorporated in the development of this report, it was developed in several steps.

The first of these was a series of workshops to engage stakeholders and to gain their perspectives on invasives management issues in the Wet Tropics bioregion. Thirty-seven individuals representing ca. 18 organisations covering management, planning and policy, research and interested community interests attended the meeting in November of 2006. The meeting was structured to gain input on perceived current and future threats, capacity to meet those threats and the research needed to ensure management success both now and into the future. Individuals were seated in groups of expertise, e.g., those with weeds experience sat together. Each individual provided their written personal perspective on the threats and needs and contributed to their group's discussion. Summaries of the group's discussions and recommendations were then provided in written format and verbally to the workshop. This allowed input at the individual and the subject expert group level to be obtained. The outputs of this workshop were further refined and summarised in a follow-up workshop in February of 2007.

These meetings were also used to identify sources of additional data on species and issues that are not readily available. The meetings were also supported by further face-to-face discussions. People involved in these discussions included representatives of state and local government agencies, researchers from James Cook University and CSIRO. Representatives of the Aboriginal Rainforest Council, although invited to attend, were unable to attend. However, an indigenous liaison officer has recently been appointed by the ARC to assist MTSRF processes and the RRRC and their work will address invasive species issues from the indigenous perspective in the future. The nature of economies in indigenous communities means that their perspective on invasives can differ from those of others in the community.

Finally, a review of the primary and secondary literature was undertaken. Here we sought to identify past and current research relating to invasive species and issues in the region with the aim of using this to identify knowledge gaps and research needs. This involved searches of the scientific literature and of agency reports, plans and policy documents. This report is a synthesis of all these different sources of information.

Definitions and Report Format

The IUCN (Lowe et al. 2000) defines invasive species as 'organisms (usually transported by humans) which successfully establish themselves in, and then overcome, otherwise intact, pre-existing native ecosystems'. In this report, 'invasive species' include exotic and translocated native and pest species of vertebrates, invertebrates, plants and diseases, though it is the exotic species that in general are the primary threats in the region. Focus is centred mainly on environmental as opposed to economic pests (those that have the potential to damage primary industries), and their impact or potential impact on natural systems and processes within the Wet Tropics bioregion.

For the purpose of this report, the proposed MTSRF study areas contain the terrestrial and freshwater ecosystems occurring within the following legislative regions: the area included in the Wet Tropics bioregion (Interim Biogeographic Regionalisation for Australia (IBRA, v6.1, DEH 2006), the Far North Queensland Natural Resource Management (FNQ NRM) boundary (DNRW 2006), the Wet Tropics World Heritage Area (WTMA 2006), and a southerly extension to incorporate the rainforest area of Mt Elliot, regarded as a southern outlier of the Wet Tropics bioregion on floristic and faunistic grounds. Within the MTSRF Rainforest Projects the combined areal extent of these regions is extended by a 20 km buffer to minimise edge effects in the modelling of environmental conditions and species distributions. To ensure consistency across the projects we have adopted this same coverage for the purposes of this report. It does not include the estuarine or the marine zones of these areas except where invasives are shared with terrestrial or aquatic habitats (Figure 1). The contents of this report are presented in eight main sections:

- Executive Summary
- Overview of the current situation
  - Terrestrial vertebrates
  - Terrestrial weeds
  - Aquatic weeds
  - Aquatic vertebrates
  - Invertebrates
  - Disease
  - Economics of invasive species control
  - Strategies for invasive species research
  - Research summary
  - References
  - Appendix

Within each of these sections, there is:

- An overview of policy frameworks at national, state, regional and local levels;
- Priority invasive species listings;
- Actions and outcomes at national, state, regional and local levels;
- Synthesis of management outcomes;
- Potential future threats and capacity to meet them;
- Synthesis of research contributions to management; and
- Research needs.

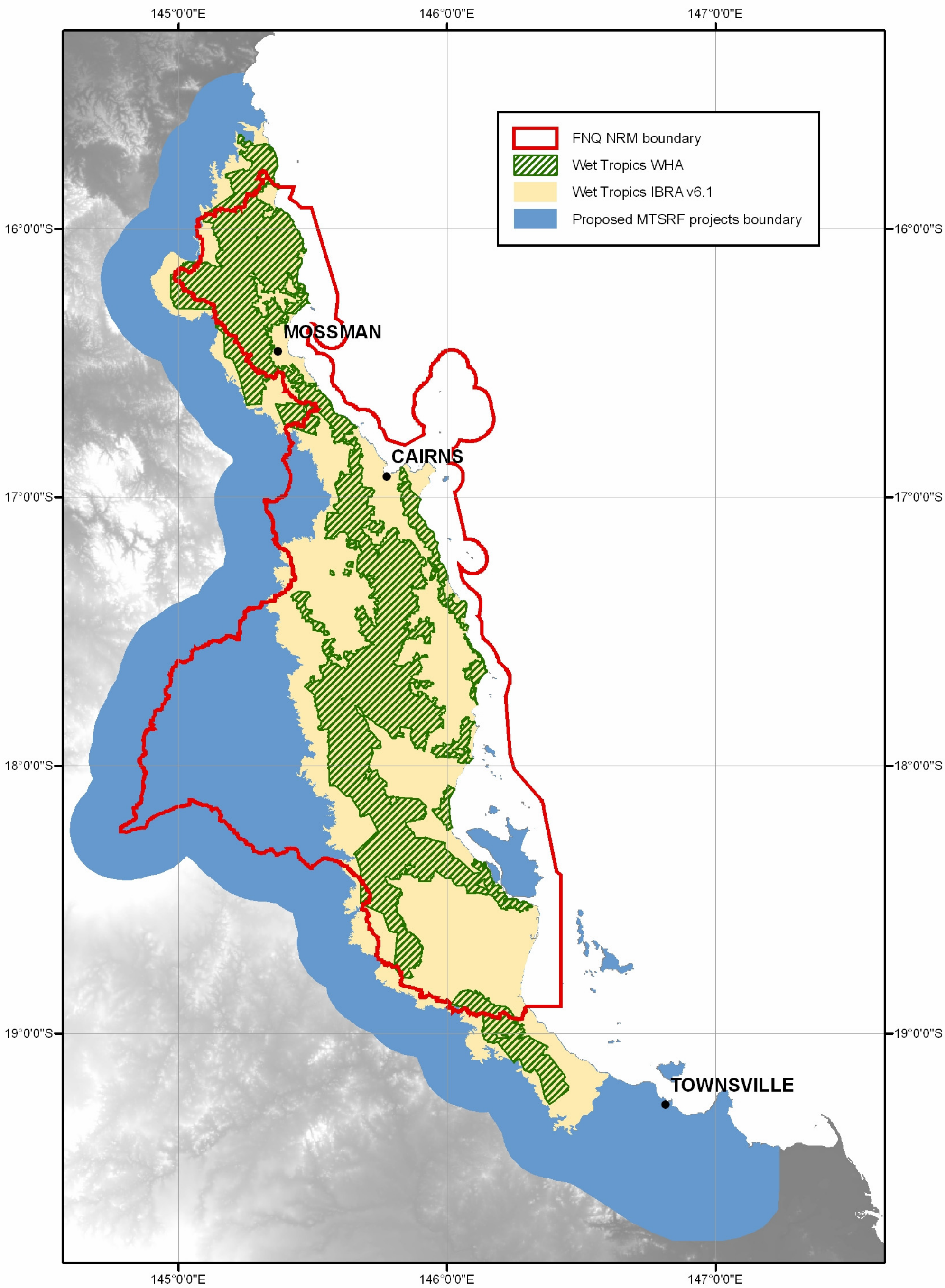

Figure 1: Map of the MTSRF study areas within the Wet Tropics, North Queensland (CSIRO 2006).

Overview of the Current Situation

Terrestrial Vertebrates

The main terrestrial vertebrate pests in the Wet Tropics Region (WTR) are all well established and have been identified as the pig, cat, cane toad and wild dog/dingo, based on their current impacts and the lack of effective methods of control (Harrison and Congdon 2002). Despite their pest status, little active research into the impacts of these species in the context of the WTR has been conducted, little is known about their biology or ecology in the region and control efforts are generally local in scale. Feral pigs are perhaps the best understood and remain a major pest in the WTR where they cause significant damage to the environment through their destructive diggings and may be carriers or vectors of diseases such as *Phytophthora cinnamomi*, foot and mouth disease and Japanese encephalitis. Control of feral pigs in the WTR has not been achieved due to lack of effective control methods that are suited to rainforest environments and the difficulty of access and rough terrain (Mitchell et al. 2006c, submitted). Research by Hudson (2005) has identified feral deer as an emerging significant threat to the region. Apart from the cane toad, little is known about the life history of most of the other vertebrate pest species and their ecological impacts to the WT rainforest.

Terrestrial Weeds

The number of invasive weeds established in the WTR region continues to increase (WTMA 2002). This is most likely a factor of so called ""sleeper species" transitioning to invasive status, improved surveillance and recognition and continuing introductions (Wonham and Pachepsky 2006). Weed management involves a more strategic approach now than in the past, focusing on those weeds where successful control can be achieved, particularly weeds with the potential to invade ecosystems that are currently intact. The main concerns are environmental weeds which are those that have the potential to invade and change the functioning of WTR ecosystems. These include garden plant escapes, introduced exotic species that have become naturalised and native species now presentpresent beyond their previous ranges. There are now over 500 exotic plant species that have become naturalised in the WTR (Queensland Herbarium, cited in Werren 2001), nine of which are on the Weeds of National Significance (WoNS) list (Williams and West 2000) and at least 210 exotic weed species in the WTR rainforest have been collected (A. Ford, pers. comm.).

Aquatic Weeds

Seven species of aquatic weeds were identified by (Werren 2001) as being of high risk in the WTR. They include water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*), salvinia (*Salvinia molesta*), pondweed (*Elodea canadensis*), arrowhead (*Sagittaria graminea* ssp. *platyphylla*), cabomba (*Cabomba caroliniana*) and alligator weed (*Alternanthera philoxeroides*). However, although they are listed as high risk species, *E. canadensis, S. graminea* ssp. *platyphylla* and *A. philoxeroides* do not appear to be having a significant impact in the WTR at present. Limnocharis (*Limnocharis flava*) is an aquatic weed and one of four invasive species targeted in the successful Four Tropical Weeds Program (4TWP) that was established five years ago.

Aquatic Vertebrates

Tilapia species and exotic aquarium fish have been identified as major threats to native fish species and ecosystems in the WTR (Harrison and Congdon 2002). Tilapia have increased in number and geographic distribution, invading many of the region's waterways and water storages. The translocation of tilapia and native fishes to areas beyond their natural range, without environmental risk assessments before release by recreational fishers and fish stocking programs, has emerged as another major threat to previously unaffected WTR waterways and is contributing to the rapid spread of invasive fish species (Burrows 2002).

Invertebrates

Historically, research has been centred on those invertebrate pest species that have the potential to damage primary industries and, to a lesser extent, those that pose a threat to human health. Tramp ants, such as crazy, fire and electric ants are the invertebrates that have been identified as the major environmental pests in the WTR. Exotic earthworms have the capacity to change ecosystem processes, soil nutrient availability and species composition within rainforests, however, virtually nothing is known about their ecological impacts in the WTR.

Recent attention has been drawn to the presence of two species of tramp ants in the WTR, as several incursions of both crazy and electric ants were reported in the Cairns area between 2005 and mid-February 2007. These ants are regarded as serious environmental pests as they are known to have had significant negative impacts on local biodiversity and human quality of life overseas in areas where they have invaded (e.g., New Caledonia (Le Breton et al. 2003) and Christmas Island (Anon. 2005). A Threat Abatement Plan, to reduce the impact of six species of tramp ants on biodiversity in Australia and its territories, was released in 2006 (C of A 2006b, 2006d). It recommends the development and implementation of methods of early detection, rapid response and follow-up treatments to outbreaks and education of the Australian community about the impacts of tramp ants.

Disease

Two soil-borne pathogens (*Phytophthora cinnamomi* and *Batrachochytrium dendrobatidis*) have caused significant mortality of woody plants and amphibians, respectively, during the initial stages of their invasion in areas of the WTR, and they continue to be the focus of research and management.

P. cinnamomi is a widespread soil-borne pathogen which infects woody plants causing plant death and has been linked to localised patches of forest dieback in the WTR. Initial studies of post-dieback recovery concluded that whilst some parts of the forest have the capacity to recover, in general, impacts of the disease have been catastrophic and could possibly continue to result in local plant extinctions (Worboys 2006). Another study by CSIRO suggests that whilst initial infection appears to have dramatic impacts, in the medium term, *P. cinnamomi* may have only a minor impact on the forest as recruitment post-infection was reported to be greater in areas that had been infected, compared to non-infected areas and stem density and basal area in the infected areas were higher than at pre-infection, 28 years earlier (Metcalfe and Bradford, unpublished).

Chytrid fungus, *B. dendrobatidis,* is a pathogen which has been determined to be responsible for the deaths of large numbers of stream-dwelling frogs in the WTR. The fungus appears to have been in the WTR since the early 1990s and is regarded as causing the the extinction of one WTR frog species, the sharp snouted day frog (*Taudactylus acutirostris)* and the local extinctions of at least three frogs from upland WTR habitats, (*Nyctimystes dayi, Litoria nannotis, Litoria rheocola*) although their lowland populations appear stable. Recent surveys in the WTR region located a frog species, the green-eyed tree frog, *Litoria genimaculata,* which has recovered from infection and it is thought this might be due to increased resistance to the disease or a change in environmental conditions (McDonald et al. 2005).

Some other rainforest frog species that may not be susceptible to the disease have also been located (K. McDonald, pers. comm.).

Terrestrial Vertebrate Species

Priority Listings

This section reviews past and current invasive species priority listings, the criteria involved in the listings, what actions have been taken to meet the threat posed by the identified species and the outcomes of these actions. In general, the species identified in the priority listings do not appear to have changed significantly over time, other than through the addition of new species. However, this increase in numbers may not reflect a true increase in invasive species, it might be the result of delay in detection of the species (which usually arrive and become established to some degree before detection) or the increase might be due to improved methods of surveillance and detection (Wonham and Pachepsky 2006).

The Wet Tropics Vertebrate Pest Risk Assessment Scheme (WTVPRAS) was developed by Harrison and Congdon (2002) to establish relative pest status and potential impact of exotic vertebrates within the WTR. Their scheme prioritises invasive vertebrates in two main stages. First, the pest status of each species is assessed relative to and within the WTR context including:

- Previous pest history;
- Reproductive and dispersal potential;
- Ability to capitalise on variation in climatic and/or biological events;
- Ability to vector diseases or parasites; and
- Ability to threaten existing species via predation, competition, and/or habitat degradation.

Impact indices for each species are then generated, scoring them against four criteria based on published ecological data from work conducted in the WTR and elsewhere:

- Current impact;
- Potential future impact;
- Feasibility of control; and
- Non-target impacts of control methods.

Under the WTVPRAS, species that have a more serious current and potential future impact, are more difficult to control and whose control may have greater non-target impacts, are ranked with higher priority than are other species. Species were ranked as major pests, sleeper species, or of moderate or low concern. This risk assessment was applied only to pests that are listed in schedule two of the Wet Tropics Management Plan (cited in Harrison and Congdon 2002) and/or had been previously reported as being present within the boundaries of the WTR (Long 1981, Herbert and Peeters 1995, Williams et al. 1996, Arthington et al. 1999, all cited in Harrison and Congdon 2002). Potential future pests (or sleeper species with moderate current impacts but which could potentially have a more significant high impact in the future) included certain species currently present within the WTR or adjacent regions of Queensland.

Major pest species were ranked most highly because of their current impacts and their lack of controllability. The top four major pest species were identified as the feral pig, cat, cane toad, and wild dog/dingo. These four species have wide distributions and are known to have negative effects on endangered and threatened species and habitats. In each case, these species are:

- Well established in the majority, if not all habitats of the WTR, and the biomes surrounding it;
- Have been present for periods of decades through to thousands of years; and
- Appear to have reached carrying capacity.

According to Harrison and Congdon (2002) eradication of these species does not seem possible in the short term given the limited resources available. They recommend that management effort should aim to reduce their impacts in sensitive areas, include determination of what are acceptable levels of infestation and what levels of impact from control measures on native species is acceptable. Exotic fish and rabbits were also identified as major pests. Although they have lower impact scores, they are equally difficult to control. Low controllability refers to the lack of available target-specific techniques or the high impact on native non-target species as a result of the control used. For example, it is difficult to control exotic fish without affecting native fish in the same waterway. The lack of data about the impacts of exotic fish and rabbits on native species may have resulted in an underestimate of their impacts.

A variety of other species were identified either as sleepers or of moderate to low concern (Table 1). In order of perceived threat the sleeper species that were identified are: gambusia, two tilapia species, guppy, swordtail, rabbit, platy, common myna, fox, black rat, brown rat and nutmeg mannikin. Overall, the WTVPRAS suggested that exotic fish, including the two tilapia species, represented one of the main invasive species threats to the WTR because of their capacity to dominate riverine communities, the lack of control methods available to combat their spread and the highly negative impacts of current control options on non-target species. Though less commonly recognised as a threat, species such as the swordtail, guppy, and platy were considered to pose only a slightly lower pest potential than tilapia. The fox, a significant predator elsewhere in Australia, was identified as a sleeper species, and had a low impact score, largely because it was present only in low numbers at the time of assessment. For rusa deer and goats, a lack of identified current impacts resulted in a relatively low score despite Harrison and Congdon’s opinion that they have the potential to cause significant problems should larger populations become established. Less significant, but species with the potential to be future threats, were the black rat, common myna and rabbit.

Moderate and low risk species, which included a range of birds and mammals, were those species for which control was considered relatively simple or which lacked identified current or future impacts. These species included sparrows, house mice, brown rats and turtledoves, all of which currently affect only urban and fringing areas and appear to have limited potential to spread into native vegetation. Nevertheless, the overall impact of these species will only increase with the continued expansion of urban and rural residential development in the region. The house gecko, brown hare, rock dove, horse, fallow and chital deer were all identified as having a minimal impact and unlikely to pose a serious environmental threat in the foreseeable future.

The WTVPRAS indicated that the main sleeper species were exotic fish (see Aquatic Vertebrate section), along with the rabbit, fox, certain birds and rats and suggested that exotic fish are the main invasive species threat to the WTR’s aquatic ecosystems, due to their capacity to dominate riverine communities and their low controllability. Lack of information about how exotic species affect native species may have also resulted in an underestimation of their impact indices. Moderate and low risk species that appear to be easier to control but which scored low due to lack of identified current impact, included a range of birds and mammals. These apparently low impact species are currently associated with human settlement in urban and fringing areas and appear to have limited potential to spread to natural areas. However their impact would be expected to increase as urban areas expand.

Table 1: Ranked overall pest status of vertebrate pests derived from a combination of all categories of impact (current and potential) and control (difficulty and negative control effect) (Harrison and Congdon 2002).

Scientific name	Common name	Level of impact
Sus scrofa	Pig	**major**
Felis catus	Cat	
Bufo marinus	Cane toad	
Canis familiaris	Dog/dingo	
Gambusia holbrooki	Gambusia	**sleeper**
Oreochromis mossambicus	Tilapia	
Tilapia mariae	Tilapia	
Poecilia reticulata	Guppy	
Xiphophorus hellerii	Swordtail	
Oryctolagus cunculus	Rabbit	
Xiphophorus variatus	Platy	
Acridotheres tristis	Common myna	
Vulpes vulpes	Fox	
Rattus rattus	Black rat	
Rattus norvegicus	Brown rat	
Lonchura punctulata	Nutmeg mannikin	
Passer domesticus	House sparrow	**low**
Mus musculus	House mouse	
Lupus capensis	Brown hare	**moderate**
Hemidactylus frenatus	House gecko	**low**
Streptopelia chinensis	Spotted turtle-dove	
Equus caballus	Horse	
Columba livia	Rock dove	
Capra hircus	Goat	**sleeper**
Pycnonotus jocosus	Red-whiskered bulbul	**mod**
Cervus timorensis	Rusa deer	
Cervus axis	Chital deer	**low**
Dama dama	Fallow deer	

The WTVPRAS represented a first attempt at developing a coherent assessment framework for comparing and prioritising current and potential invasive vertebrate species. As such it represents a significant step in invasive management in the region and has had a significant impact. It and its application are not, however, without their shortcomings. Primarily application of the WTVPRAS is limited by a severe lack of information about invasive vertebrates in the WTR (Harrison and Congdon 2002). This includes a lack of baseline data on historic and current distributions and abundances of native species against which to gauge exotic species impacts and a lack of data on the ongoing impacts of invasive species. Thus, much of the data use in the WTVPRAS, by necessity, was based on anecdotal evidence and expert opinion or data from elsewhere in Australia or overseas. Though unavoidable, this casts a degree of uncertainty over the actual impacts that invasives are currently having or are likely to have in the future. In addition, these data gaps mean that assessment of control effectiveness becomes difficult and must be done, not on measures of impact reduction, but rather on the basis of catch rates.

An additional concern, and one that is specific to the WTVPRAS, is that the WTVPRAS rankings of species are heavily influenced by the controllability of a species. Thus species which are difficult to control are likely to rank highly for a given score across the other criteria. Species that have been present for a long time may have an elevated score when their actual impact is now lower due to their long-term presences and the adjustment of systems to their presence, e.g. cane toads. Thus, species which may not now be exerting a directional pressure on the system but which are difficult to control may rank more highly than species which are relatively easy to control, but which continue to cause threatening declines in native species or ecosystems. Avoiding such an outcome relies upon the judgement of the user of the WTVPRAS.

Table 2. Emerging, established and potential feral animals likely to threaten WH values in the WTR, excluding Australian native animals translocated outside their natural range [from the WT Conservation Strategy, WTMA 2004].

Common Name	Zoological Name	Priority		Status			Action			
		High	Medium	Emerging	Established	Potential	Eradicate completely	Control spread into WTR	Prevent introduction, eradicate new outbreaks	Control locally where possible
Chital deer	*Axis axis*	X		X			X			
Rusa deer	*Cervus timorensis*	X		X			X			
Goat	*Capra hircus*	X		X			X			
Red fox	*Vulpes vulpes*	X		X				X		
Rabbit	*Oryctolagus cuniculus*	X		X				X		
Yellow crazy ant	*Anoplolepis gracilipes*	X				X			X	
Fire ant	*Solenopsis invicta*	X				X			X	
Papaya fruit fly	*Bactrocera papayae*	X				X			X	
Pig	*Sus scrofa*	X			X					X
Cat	*Felis catus*	X			X					X
Cattle	*Bos taurus*	X			X					X
Dog	*Canis familiaris*	X			X					X
Mosquito fish	*Gambusia holbrooki*	X			X					X
Guppy	*Poecilia reticulata*	X			X					X
Tilapia spp	*Tilapia mariae* *Oreochromis mossambicus*	X			X					X
Palm leaf beetle	*Brontispa longissima*	X			X					X
Cane toad	*Bufo marinus*		X		X					X
Indian mynah	*Acridotheres tristis*		X		X					X
Black rat	*Rattus rattus*		X		X					X
Exotic earthworm	*Pontoscolex corethruthrus*		X		X					X

Policy Frameworks

National

The National Feral Animal Control Program (NFACP) is a federal government initiative that aims to reduce the damage to agriculture caused by pest animals such as feral rabbits, foxes, pigs, mice, birds and goats (the Program is currently undergoing review, so this information is based on information last updated in August 2006). This program provides a framework under which species-level control strategies can be developed and implemented at all levels of government. The program acknowledges that eradication of pest species that have become established over a long period of time is not feasible and so focuses on developing integrated strategic approaches to manage and reduce the impacts of nationally significant pest animals, improve the effectiveness of control techniques and focuses on areas where the animals 'are causing actual rather than perceived damage'. The main features of the NFACP are:

- Gathering basic ecological data on pest species, relating their movements and density with the extent and nature of damage, identifying stakeholders and monitoring of impacts to evaluate the effectiveness of management strategies.
- Emphasise ways to reduce impact rather than simply killing the animals, especially if animal density is not related to extent of damage.
- Strategic management which involves consideration of management area and timing, long-term treatment and using a combination of control techniques, e.g. habitat manipulation as a fox control strategy, operation at a local or regional scale for maximum efficiency and encouraging stakeholder participation in defining problems and solutions.
- Consideration of commercial use of pest species to reduce their densities if appropriate, e.g. shooting for game meat.
- Development of humane pest management techniques and strategies, where cost and efficiency is comparable to current approaches.

When an animal, plant or other organism is identified as causing a key threatening process that impacts on a threatened species or ecological community, the federal Minister for the Environment and Water Resources may decide to establish a national Threat Abatement Plan (TAP), under the Commonwealth *Environment Protection and Biodiversity Conservation (EPBC) Act 1999.* TAPs provide a framework for research and management actions that aim to reduce the impacts of the identified threatening process. They are developed after consultation with the Threatened Species Scientific Committee and interested government agencies. Before being adopted, the plans are available for comment from interested parties. To date, these TAPs have been approved (DEWR 2007):

- Beak and Feather Disease affecting endangered psittacine species.
- Competition and land degradation by feral goats.
- Competition and land degradation by feral rabbits.
- Dieback caused by the root-rot fungus (*Phytophthora cinnamomi*).
- Incidental catch (or by catch) of seabirds during longline fishing operations.
- Infection of amphibians with chytrid fungus resulting in chytridiomycosis.
- Predation by European red fox.
- Predation by feral cats.
- Predation, habitat degradation, competition and disease transmission by feral pigs.
- Reduction in impacts of tramp ants on biodiversity in Australia and its Territories.

However, the approval of a TAP does not necessarily mean that its recommendations are fully implemented or achieved. This is most likely due to inadequate consultation during the development process and inadequate resources (Agtrans Research and Dawson 2005, Abbott 2007).

Queensland State

The *Land Protection (Pest and Stock Route Management) Act 2002* provides a framework for control of major pest animals and plants throughout Queensland with clear responsibilities allocated to State and local government departments and landholders.

At the State level, this Act requires Pest Management Plans (PMPs) to be developed and administered for State-owned areas, control of declared pests on State- managed land by the state authority, and participation in local government pest planning processes. Local governments administer their PMPs and the Act, control declared pests on council managed land and ensure control of declared pests on freehold/leasehold land. There is also provision for local councils to have a Local Law (*Control of Pests*) in place where the pest is found within their shire and has the potential to be an environmental pest or harmful to human health. Individuals are responsible for control of declared pests on their land and complying with any pest control notice served upon them.

Pest animals may be State-declared as a pest in one of three classes, depending on the severity of their current or potential impact. There are three categories of declared pest:

- Class 1: Pest is not commonly present or established in the State and has the potential to cause an adverse economic, environmental or social impact in the State, another State or a part of the State.
- Class 2 or Class 3: Pest is established in the State and is causing, or has the potential to cause, an adverse economic, environmental or social impact in the State, another State or a part of the State. In deciding whether to declare an animal or plant to be a Class 2 or Class 3 pest, consideration is given to:
  - The significance of the animal's impact or potential impact.
  - The area affected, or likely to be affected, by the impact.
  - The extent to which the animal has spread or is likely to spread.

The Queensland Pest Animal Strategy (QPAS) 2002-6 (DNRM 2002) provides a framework for the management of pest animals and requires cooperation between the state and local governments, industry, community and individuals to work toward reducing the impacts of pest animals on the environment and primary industries to an acceptable level. The QPAS covers declared pest species under the *Land Protection (Pest and Stock Route Management) Act 2002*, such as feral pigs, wild dogs, rabbits, foxes, introduced mammals such as feral cats, reptiles, birds such as the common myna and amphibians and exotic fishes, as well as native species that are regarded as problem animals, usually to the primary industries.

This strategy differs from the NFACP in that native species, such as crocodiles, possums, snakes, and spectacled flying fox are included and are referred to as 'problem animals', and these are managed for 'conservation goals', their impacts usually being regarded as temporary and localised.

The QPAS has six main components which are:

- Awareness of the problems and making information available;

- Gathering of ecological data, distribution and abundance data, monitoring and assessment of impacts to aid with decision-making;
- Strategic planning and management framework, including appropriate legislation;
- Prevention and early intervention to minimise spread and minimise impact;
- Development and use of effective integrated management systems; and
- Commitment to long term co-ordinated pest animal management.

Regional

Preventing the establishment of new arrivals, eradicating new and localised outbreaks of invasive feral animals and controlling the spread of established invasive feral animals which threaten the World Heritage values are amongst the major conservation priorities contained within the WT Conservation Strategy 2004 (WTMA 2004). The Far North Queensland Local Government Pest Plan Advisory Committee (FNQLGPPAC) RPMP (2006) feeds into this strategy in terms of dealing with invasive species in areas within the WTR, outside the World Heritage Area.

The Far North Queensland Regional Organisation of Councils (FNQROC) and Hinchinbrook Shire have developed an integrated pest management plan that deals with invasive plant and animal species in tropical northern and north-eastern Queensland. The aim of the plan is to identify, record and prevent the establishment of invasive species within the FNQROC and Hinchinbrook Shire boundaries and to ensure all stakeholders meet their obligations and responsibilities in controlling invasive species according to the *Land Protection (Pest and Stock Route Management) Act 2002*. This plan comprises eight strategies including:

- Pest prioritisation;
- Pest prevention;
- Early detection and intervention;
- Prevention or inhibition of pest spread;
- Information handling and communication;
- Community awareness and education;
- Stakeholder involvement extension; and
- Cross-program consistency implementation.

For the rationale behind these strategies and more information, refer to FNQLGPPAC (2006).

Within this plan, pest animals are assigned to one of three priority classes:

- High priority exotic species, widespread and regionally significant;
- Medium priority exotic species, less controllable, less widespread or occur in localised areas; and
- Lower priority native pest species that present particular economic problems to primary industry, requiring some local government control assistance (e.g. cane rats in sugarcane), although native species are recognised as a State government responsibility rather than a local government one.

Local

Under the *Land Protection (Pest and Stock Route Management*) *Act 2002*, local governments are responsible for undertaking pest management planning for all land within their local government area, regardless of tenure. These local government area pest management plans (LGAPMPs) include assessments of the priority of control for each pest species and the measures that are to be undertaken. They assist local government in assessing the most destructive pests in their area and developing priorities for their management.

Priority Terrestrial Vertebrate Species

Feral Pigs (*Sus scrofa*)

Despite regional trapping programs and hunting, feral pig densities in the WTR are high (WTMA 2004, 2006) and they remain a species of major concern due to the perceived seriousness of their impact on the rainforest environment where they are known to target specific microhabitats (Laurance and Harrington 1997, Mitchell et al. 2006a, submitted). In these areas, in particular, they cause habitat degradation through their digging and wallowing and reducing rainforest seedling survival (Mitchell et al. 2006b submitted). In Arnhem Land, they have been linked to the local decline of a turtle species (Fordham et al. 2006). They cause major damage to a wide range of agriculture, from cane farms and bananas (Mitchell and Dorney 2002) to orchards (Heise-Pavlov and Heise-Pavlov 2003). The cost of feral pig damage and management has been estimated as $4,099 per annum on banana farms and $10,632 on cane farms (Mitchell and Dorney 2002). Feral pigs are known to carry and transmit parasites and diseases including foot and mouth (Pech and McIlroy 1990, Pavlov et al. 1992, Doran and Laffan 2005) and a variety of zoonoses (Heise-Pavlov and Heise-Pavlov 2003). They are capable of spreading the pathogen, *Phytophthora cinnamomi* (Brown 1976, Tisdell 1977) and have been reported to disperse weeds, including Weeds of National Significance (Lynes and Campbell 2000, Setter et al. 2002). They also compete for native food with other animals such as bettongs (Laurance and Harrington 1997) and cassowaries (Pavlov et al. 1992). In addition to their direct ecological impacts, pigs are known to act as reservoirs for important agricultural and human diseases, e.g. foot and mouth (Pech and Hone 1988) and in the nearby Western Cape, Japanese encephalitis (Hanna et al. 1998, Ritchie et al. 2003).

Actions and Outcomes

National

A national Threat Abatement Plan (TAP) to reduce the predation, habitat degradation, competition and disease transmission by feral pigs was released in 2005 (C of A 2005). Feral pigs are now widespread throughout Australia and the TAP acknowledges that complete eradication is not feasible, with the exception of localised areas or on offshore islands (Bomford and O'Brien 1995, Olsen 1998, Braysher and Saunders 2003, all cited in C of A 2005). Therefore it recommends that the animals be maintained at the lowest levels that available resources allow, based on current knowledge and methodology.

The main research issues regarding feral pig control continue to be centred around:

- Baiting strategies;
- Poisons used for baiting;
- Methods of poison delivery;
- Biocontrol;
- Fertility control;
- Animal welfare;
- Coordination in policy;
- Training and extension work;
- Best practice survey methods; and
- Economic analysis of pigs as a resource (Lapidge 2003).

State

In Queensland, the feral pig is a declared Class 2 pest animal under the regulations of the *Land Protection (Pest and Stock Route Management) Act 2002.* Landholders and the State are responsible for keeping their land free from feral pigs (Section 77, Land Protection Act). Local governments have the power to issue landholders with a notice to control feral pigs on their land or face a maximum penalty of $60,000 (Section 78). Under the same Act, it is illegal to feed, release or keep feral pigs. Since feral pigs are highly mobile, it has been found that coordinated pig control measures over large spatial areas have been most effective (DNRME 2004).

The Queensland Feral Pig Management Strategy (QFPMS) was developed to reduce the environmental, social and economic impacts of feral pigs. It includes:

- Raising community awareness and acceptance of the need to control feral pigs;
- Coordinated and collaborative pest management planning;
- Adequate resource allocation and appropriate resource use;
- Targeting areas for local eradication; and
- Using control measures suited to local conditions.

Strategic research includes defining the pig problem through collecting ecological and life history data for pigs in all habitats in Queensland, and finding effective management solutions by improving control techniques. The strategy is subject to review by State and LGA Pest Management Committees.

Regional

According to the FNQROC PMP, feral pigs are categorised as 'high priority' species (FNQLGPPAC 2006), meaning that numbers are to be controlled locally where possible (WTMA 2004).

In the WTR, control measures have included poison baiting, trapping, shooting and hunting with dogs and fencing of critical habitats and areas (WTMA 2004). Baiting, which works in southern states and in drier open country where food is less abundant, is not as effective in the WTR and a target-specific bait has not yet been developed which could be used in the rainforest. Combinations of trapping and shooting on rainforest edges and dogging within crops have had some success (J. Mitchell, pers. comm.). The QPWS has undertaken feral pig control programs in coastal range national parks and state forests between Townsville and Cairns.

Local

Feral pigs remain a major high priority vertebrate pest in the WTR as there are currently no effective methods of eradication that are practical for use in the rainforest, due to inaccessible terrain and their elusiveness (Mitchell and Dorney 2002). In a comparison of feral pig control techniques on cane and banana farms in tropical north Queensland, Mitchell and Dorney (2002) determined that trapping undertaken by private landholders was the most cost effective technique, with an approximate cost of $141 per pig caught, compared with other techniques including community-based trapping ($209), dogging ($257), poisoning, fencing and shooting ($1,048).

In 2004, a Memorandum of Understanding for the control of feral animals (feral pig, feral cat, wild dogs and dingo hybrids) was signed by Cairns City Council (CCC), DNRMW, EPA and WTMA for implementation at Copperlode Falls Dam and Mt Whitfield Protected Areas Estates. The aim is to reduce the impact of feral animals particularly in the zones where

Protected Areas are adjacent to urban areas, using an integrated pest management program which includes trapping, shooting where appropriate, baiting and fencing conducted by fully trained and accredited staff from the appropriate agency. From a local landowner perspective, trapping and shooting are used to control dogs.

The Community-Based Feral Pig Trapping Program is a joint project funded primarily by WTMA, DNRMW, NHT and QPWS and includes participation of traditional owners, private landowners and local shire councils, using best practice management techniques. The Program has been successful in culling large numbers of pigs in localised areas, e.g. a region-wide program coordinated by WTMA and DNRW caught and destroyed 6,500 pigs between 1994-9, and according to WTMA (2004), the program had removed over 15,000 pigs up to 2004. However, without having reduced pig numbers below critical population levels, this effort would not be expected to have had a significant and lasting impact on pig populations (WTMA 2004), a suggestion that has been anecdotally confirmed in the field.

Feral and Stray Domestic Cats (*Felis catus*)

Although feral and stray cats were ranked by Harrison and Congdon (2002) as having major ecological impacts, are declared Class 2 pests and are also ranked by the FNQROC as high priority exotic pest species (FNQLGPPAC RPMP 2006), the priority to deal with them appears not to reflect their assumed importance as vertebrate pests in the WTR. An almost complete lack of information about the actual environmental impact of cats in the WTR highlights the importance of quantifying their impacts in order to determine their true pest status and the need for their control.

There is no doubt that cats are effective predators and that in Australia generally they have had significant ecological impact. Though it is controversial, cats are increasingly implicated in the extinction of mammals of <1 kg during the first 100 years of European settlement (Short et al. 2002). with 30 of 100 pathogens that cats were carrying being found in native fauna (Moodie 1995). In southern Australia, studies have shown that cats are significant predators of native wildlife, killing small mammals, birds, reptiles and invertebrates, the majority being under 200 g (Dickman 1996), while in central Australia they are known to feed on animals up to their own body mass (Paltridge et al. 1997). In a five year study, cats were shown to be responsible for 75% of attacks on native species brought to animal welfare agencies, shelters and zoos for care (Dowling et al. 1994). In Brisbane, cats are regarded as being responsible for the total absence of all small ground-dwelling native mammals in the Toohey forest (McRae and Smith 1987, cited in Dickman 1996), as being vectors of disease (Bell et al. 2006), with 30 of 100 pathogens that cats were carrying being found in native fauna (Moodie 1995, cited in Dickman 1996). In a review of feral animal control in Australia, (Reddiex et al. 2006) found that feral cat control received the lowest funding levels.

Actions and Outcomes

National and State

A national TAP was released in 1999 aimed at reducing the impact of feral and stray cats on endangered and threatened native species (EA 1999).

In Victoria, the Sherbrooke Shire Council (SSC) was one of the first councils to be successful in introducing an Animal Welfare Law aimed at controlling cats to reduce the number of lyrebirds being killed by cats. This law included a night time cat curfew and requirements that cats be registered and de-sexed. Similar laws have been introduced by local councils around Australia, including Caloundra and Magnetic Island in Queensland (Scriggins and Murray 1997).

No formal ecological or social studies were undertaken to assess the effects of this form of cat control within the Sherbrooke Shire in the years 1991-4, however observational and anecdotal information suggest a decrease in cat predation on lyrebirds and other native fauna (Pergl 1994). The success of SSC's introduction of cat control measures was achieved through extensive community consultation, community education and provision of a local law that outlined clearly what was expected of responsible pet owners. (Pergl 1994).

Regional

Despite evidence from elsewhere in Australia that feral and stray domestic cats are significant predators of native wildlife and the fact that they are regarded as one of the major vertebrate pests in the WTR (Harrison and Congdon 2002) little (if any) management action has been undertaken to keep them under control or to eradicate them in the WTR. While being listed in Shire Council management strategies no formal control programs have operated in the region. Control actions, to the best of our knowledge, are limited to opportunistic trapping and shooting by land owners.

This inaction is most probably linked with the lack of studies quantifying the actual ecological impact of cats in the WTR and confirming (or not) the validity of the ranking by Harrison and Congdon (2002). If surveys show that cats are killing a significant amount of native wildlife, and that their eating habits are causing continuing population declines, the results could contribute to overcoming the perception by many in the community that cats are cute, cuddly and harmless, a possible misconception most likely based on cats being seldom seen in the rainforest.

The FNQROC PMP rates cats as high priority exotic species and recommends that numbers should be controlled locally where possible. Apart from this, there are no formal cat control programs in the WTR and landowners are responsible for control or disposal of the cats.

Local

The control of feral cats at Copperlode Falls Dam and Mt Whifield Protected Areas Estates, was also covered by the Memorandum of Understanding referred to in the feral pigs section. From a local landowner perspective cat traps and shooting are used to control cats.

There has been only limited management of cats implemented in the WTR region, thus no change in their status or their overall impact is expected. The experience of the Sherbrooke Shire Council's cat management program suggests that were such a program to be introduced in the WTR, it might meet with some success in the vicinity of human dwellings and urban areas.

Wild Dog / Dingo (*Canis familiaris*)

There is little evidence that dingoes are major environmental pests although they are known agricultural pests. This is perhaps a product of the long period over which wild dogs/dingoes have been established in Australia, in the order of 3,500-4,000 years (Corbett 1995). Dingoes are known to prey on a wide range of native mammals in the WTR especially terrestrial and edge dwelling species and, in fragmented contexts, even arboreal species such as tree kangaroos (Newell 1999). In the rangelands there is evidence that dingoes limit kangaroo and emu populations (Pople et al. 2000). They can also be aggressive toward humans, as the recent death of a child on Fraser Island demonstrated (Burns and Howard 2003). This contrasts with the findings by Short et al. (2002) that compared to foxes, dingoes were more likely to kill domestic stock than native mammals. The costs of livestock loss, diseases spread by wild dogs and dog control are well documented and are reported to cost Queensland approximately $33 million per year (DNRME 2002).

Actions and Outcomes

National and State

There is no formal national management approach to feral dogs. The NFACP focuses on rabbits, foxes, feral goats and feral pigs, but not dogs. The only formal strategic plan for the control of wild dogs in Queensland is specifically for the Wild Dog Barrier Fence in central southern Queensland and the control of wild dogs inside it. The Queensland Wild Dog Management Strategy was developed after consultation with the Rural Land Protection Board, EPA, QPWS, RSPCA, Wildlife Preservation Society of Queensland, local government and industry stakeholders. Its aim is to effectively control all wild dogs but not dingoes in 'protected areas' within the Wild Dog Barrier Fence, reduce the impacts of wild dogs outside the Barrier Fence, along the coast, in semi-urban and rural residential zones and to conserve the dingo population in Queensland.

In 2005 a Memorandum of Understanding (MoU) between DNMRW, AgForce Queensland, EPA, and local governments was introduced in Queensland for the coordinated management of wild dogs. It was introduced to minimise costs to primary industries and to a lesser extent urban communities. Dog control measures recommended by the MoU for management of wild dogs (DNRMW 2005) include dog baiting with 1080 (sodium monofluoroacetate), extension activities with landholders to encourage coordinated baiting and working with communities in semi-urban areas. Baiting is also undertaken on state lands including national parks. Regional dog baiting trials have been undertaken by DNRMW to determine how dog baits affect non-target native species such as quolls and research to find an antidote to 1080 poison is being undertaken in New Zealand, which if successful, could result in more landowners participating in baiting programs without fear of losing their own dogs.

Legal responsibility for dog control rests with land managers, including individuals, industry, local and state government agencies. However the DNRMW coordinates wild dog control, particularly 1080 baiting, between local governments and key landholders and local governments may also be involved in control operations.

Regional

Although wild dog/dingo have been identified as declared Class 2 pests and major vertebrate pests of high priority in the WTR (Harrison and Congdon 2002, WTMA 2004) and by many landholders in rural areas (J. Butler, pers. comm.) action to control them in the WTR has been localised and implemented in response to complaints of public nuisance, or threats to livestock. There is a lack of information quantifying the actual ecological impact of wild dogs in the WTR, and until there are results showing that dogs are having a significant and continuing effect on the decline of native fauna populations, there appears to be little to support dog control from a biodiversity impact perspective.

Local

The control of wild dogs/dingo and hybrids at Copperlode Falls Dam and Mt Whifield Protected Areas Estates, was also covered by the Memorandum of Understanding referred to in the feral pigs section.

In the WTR, dog control programs operate on short time and spatial scales, and are reactive in that they deal with issues as they arise in specific locations. The current range of techniques used to control wild dogs includes trapping, shooting, fencing, baiting (ground and aerial) and aversion techniques. These programs are locally effective but are not conducted in a coordinated manner or with the goal of impacting regional population sizes or dynamics. Given that dingoes have been in Australia for the past 3,500-4,000 years, it is unlikely that any effective control other than at the local and issue scale can be achieved. However there is still scope for more effective and strategic management of stray and wild-living domestic dogs, particularly at the interface between rainforest and the ever-expanding urban areas in the WTR.

Feral Deer (*Dama dama, Cervus axis, Cervus timorensis*)

Research has identified feral deer as potential sleeper species in the WTR (Hudson 2005) due to their capacity to degrade habitat through browsing, grazing and trampling, thus causing erosion, lowering water quality, and the potential to harbour stock and wildlife diseases (Caughley 1983, Chatterton 1996, both cited in Jesser 2005). Rusa deer *Cervus timorensis* were responsible for defoliation, bark stripping and stem breakages on 69 of 78 plant species in the Royal National Park, south of Sydney. Such damage occurred during seed production and seedling recruitment life history stages, resulting in changes in community composition and population dynamics. Erosion also occurred where their densities were high (Keith and Pellow 2005).

The potential impact of feral deer in the WTR is of particular concern given that Australia's tropical rainforests have no indigenous, vertebrate browsers. It might be expected that few rainforest plants would have evolved defences against such browsers. Thus changes in plant community composition that reflect patterns of resilience to browsing across species and, in extreme cases, loss of particular species from the community might be expected. At the moment, there is no Queensland legislation that deals specifically with deer so that there is no state regulation of the introduction, keeping, sale or release of deer (Hudson 2005). Deer are classed as livestock and responsibility for their management rests at regional and local levels. However, this responsibility is subject to some confusion due to inconsistent definitions of deer and legislation and policies across local government areas. Hudson (2005) recommends that the 'most appropriate legislative and regulatory approach to control feral deer in the Wet Tropics bioregion is for them to be locally declared as pests.

Actions and Outcomes

National and State

At a national level, the importation of deer and deer genetic material into Australia is restricted for reasons of animal health under the Commonwealth *Quarantine Act 1908* and subordinate regulations. The DEH also exercises regulatory control over animals which are classified as suitable for live import and issues permits for the importation of identified species. The regulations are established under the *EPBC Act 1999*, section 303. Apart from these Commonwealth controls on imports, legislation affecting deer is the responsibility of individual states (Jesser 2005).

In Queensland wild deer are classified as non-indigenous or exotic animals. This means that deer may be declared and controlled as pest species. There may also be provision for hunting or sustainable harvest (Hall 1999, cited in Jesser 2005). However, the focus is mainly on the historically established wild deer populations. Under the *Land Protection (Pest and Stock Route Management) Act 2002*, the six species that were historically established in the wild in Australia are excluded from the list of declared animals. But concern about their increasing numbers, distribution and impacts indicate that there is a need to review issues of deer management and control (Jesser 2005).

Regional and Local

As deer are relatively recent pests in the WTR, their status as declared pests and responsibility for their control is still being decided. Most control options have been developed for use in open country in southern Australia and have limited effectiveness in WTR rainforest. The most effective approach to control, particularly in structurally complex rainforests, is early intervention, whilst they are still in manageable numbers, to prevent establishment. In the WTR, populations are small and localised around farms suggesting that eradication is feasible. Such efforts have been judged worthwhile if the risk of escapes were sufficiently reduced through appropriate farm management and effective eradication methods were developed for future escapees.

Deer that have been observed in the Mission Beach, East Palmerston and Upper Daradgee areas are believed to have escaped from deer farms. Negotiations are underway with the farms to improve stock control and restrict the sale of deer as pets. The QPWS has undertaken some shooting programs and are investigating the use of traps (WTMA 2004). Feeding stations to catch roaming deer on private land in Babinda are being set up now and will be monitored during April 2007. A feral deer hotline has also been established by WTMA for members of the public to call in and advise of deer problems.

According to Hudson (2005), a coordinated regional approach by local governments within the WTR toward more efficient deer control should include:

- Consistency in the local laws and policies with regard to all aspects of deer management.
- Amendment of local laws (Keeping and Control of Animals) to require permits or licences for deer farms along with requirements to meet specific conditions such as fencing.
- Encourage local declaration of deer as Class 1 pests – priorities being rusa, fallow and sambar deer in the Johnstone, Eacham, Cairns, Cardwell and Mareeba LGAs.
- Inclusion of deer in the National Livestock Identification Scheme under the Stock Identification Regulation 2005.
- Formation of a WT Feral Deer Working Group, including as diverse a range of stakeholders as possible to address the issue and possible humane methods of feral deer control in the WTR.

Most of these recommendations are in the process of being implemented. A Feral Deer Task Force comprising representatives from CCC, CSIRO, DNRMW, DPIF, FNQROC, QPWS, UQ, WTMA has been formed and two meetings have been held to date. WTMA requested support from FNQROC to manage deer at a regional scale. This resulted in letters from FNQROC to the state government agencies (DPIF and DNRMW) requesting support in declaring deer as a Class 1 pest species and requesting that the DPIF and State Government take some responsibility for deer control. In January 2007, CCC declared hog deer (*Axis porcinus*) and fallow deer (*Dama dama*) as Class 1 pests and rusa (*Cervus timorensis*) and chital deer (*Cervus axis*) as Class 3 pests. For the hog and fallow deer this means that all landowners:

- Require a permit to introduce, feed, keep, release, supply or supply things containing reproductive material and moving or transporting them.
- Must take reasonable steps to keep land free of these deer or be subject to a pest control notice.
- May be subject to Emergency Quarantine Notice regarding the deer. A person must comply with this notice and with the authorised persons direction.

For the rusa and chital deer this means landowners are not required to control the animals unless their land is adjacent to an environmentally significant area (DNRMW 2006).

Cane Toads (*Bufo marinus*)

Cane toads were first introduced to north Queensland and Australia in 1935 as a biocontrol agent for sugarcane beetles (Lever 2001, cited in Tyler 2006). Their spread and short term environmental impacts in eastern Australia have been well documented, however long term environmental impacts have not been well studied and remain poorly understood. The response of native wildlife to cane toads at the invasion front is now under investigation as the cane toads move across the Northern Territory (Shine et al. 2006).

Cane toads kill significant numbers of native predators through the high concentrations of bufotoxins in all of their life stages, i.e. eggs, tadpoles and adult. The initial stages of cane toad invasion are most likely to have had the greatest environmental impact with naïve native predators succumbing to poisoning. Such effects have been documented for species such as quolls, monitors and snakes and other anurans (Brodie and Brodie1999, Williamson 1999, Crossland and Alford 1998, 2000). Because most studies have focused on a small subset of predators (Phillips et al. 2003) warn that many studies of cane toad toxin-related deaths may have underestimated impact given that significant predators in Australian ecosystems such as snakes have traditionally been ignored.

Exposure to cane toads appears to have induced adaptive responses in some predator species, e.g. black snakes appear to have evolved an increased resistance to toad toxin and a decreased preference for toads as prey (Phillips and shine 2004, 2006), while others appear to have learned to avoid toads or to only forage on non-toxic parts of the animal. Perversely, poisoning of native predators may indirectly result in reduced predation of turtle hatchlings (Doody et al. 2006) and increases of some anuran species (Crossland 2000). As the cane toads have been resident in the in the WTR for a long period of time, it also seems likely that their impact has reduced over time as different species and their populations adjust to their presence, as has happened elsewhere (Phillips and Shine 2005).

Cane toads, both as tadpoles and adults, are voracious predators. Experimental and field evidence indicate that toad predation has significant impacts on a wide-range of prey species,e.g. toad predation decreases invertebrate populations by as much as four fold over that level experienced when only the native anuran community is present (Greenlees et al. 2006) and a 25% decrease in reproductive output of rainbow bee-eaters, *Merops ornatus* through cane toad usurpation of their nest burrows and predation of their eggs and nestlings (Boland 2004). Such impacts directly influence the prey population and native competitors. Cane toads were ranked as having a major environmental impact and as a major vertebrate pest in the WTR by Harrison and Congdon (2002), and are ranked as medium priority established feral animals by the FNQROC PMP (FNQLGPPAC 2006) and WTMA (2004), requiring them to be controlled locally where possible.

Actions and Outcomes

Methods to control cane toads tend to be divided into two main types: those that achieve short term control (one to five years) such as trapping and fencing, and those that aim for long term control or control over large areas, such as biocontrol with a pathogen or manipulating the toad's reproductive system. The importance of studying the impacts of cane toads on the native fauna as opposed to finding a biocontrol agent, did not gain any significant support until 1993 (Tyler 2006).

National

The search for an Australian biocontrol agent as a means of controlling cane toads began in 1986. It was extended to Brazil and Venezuela in 1990 and in the mid-1990s several infectious viruses were brought into Australia to test their target specificity. Although they were found to be highly effective against cane toad tadpoles, one species of Australian frog was also killed and it was recommended that none of these viruses would be a suitable agent (Tyler 2006). Research into the possibilities of producing sterile male offspring, using specific toxins, and constructing a (disseminating or non-disseminating) biocontrol agent using molecular biological techniques, are continuing.

State and Regional

In the Northern Territory (NT), the government has funded community-based action groups such as Frogwatch in Darwin (Sawyer 2006) and the Kimberley Toadbusters at Kununurra (Boulter et al. 2006). These groups have increased public awareness and the media profile of cane toad invasion issues, have developed management strategies and conduct regular surveillance, trappings and removal of cane toads as well as monitor the effectiveness of their control actions. Although their success is localised in reducing numbers of toads in their area, the social benefits of community participation appears to be significant. The NT government has also supported the relocation of northern quolls to offshore islands and developed protocols to prevent the movement of toads to these islands. In the NT and Queensland, control strategies such as erecting physical barriers, development of more effective traps and the use of attractants, and manual removal of the toads have been successful in reducing their numbers over relatively small localised areas. It appears that management now includes acknowledging that the cane toad is an established pest that has been here over a long period of time and is one that will not be eradicated.

Local

The initial impact of cane toads appears to have reduced over time as local people and wildlife have adapted to their presence. Thus, serious efforts to control the populations of cane toads have not been undertaken, apart from local toad culls and gestures such as the recent offer by a Cairns businessman to shout patrons two beers at his hotel in exchange for taking a bag of cane toads to the RSPCA for disposal (ABC Online 2007).

Cane toads remain widespread in the WTR, although they tend to be found more in urban areas and in more open habitats near water, than in densely vegetated areas such as the rainforest. In rainforest, toads tend to be encountered along linear gaps such as old tracks and paths (D. Westcott, pers. obs.). Manipulation of habitat such as maintaining forest canopies (Preen 1981, cited in Burnett 1997), and limiting available water have been suggested to minimise or exclude toad numbers, however the effect on other species also needs to be considered. Manual removal and humane disposal involving collection of toads in plastic bags, cooling them to 4°C and freezing them in a conventional freezer, then burying or incinerating them has been recommended and is widely adopted (Hyatt et al. 2006) and has been effective on a very localised scale. Fencing to exclude toads from sensitive areas is only feasible for small areas due to the high costs involved and bounty schemes are also not sustainable due to the large numbers of cane toads.

Indian or Common Myna (*Acridotheres tristis*)

The common myna was released in North Queensland in 1883 (Herberton, Johnstone River and Townsville) in an attempt to control insect pests in cane fields. Globally, common mynas are widely recognised as a serious threat to biodiversity. In 2000, the species was included in the IUCN's list of the world's One Hundred Most Alien Invasive Species, along with the fox, the cane toad and the feral pig. The common myna was identified as a sleeper species by Harrison and Congdon (2002) and it has been reported (from other places in Australia where they are a pest) that their presence has had a negative impact on local native bird and possum populations through competition for nesting hollows (Pell and Tidemann 1997, Tidemann 2004, Harper et al. 2006). However, Parsons et al. (2006) found no relationship between the presence of small birds and common mynas in urban areas of Sydney. Olsen et al. (2006) also note that although mynas compete against parrots and other birds for nesting hollows, no studies have yet recorded a decline in the numbers of parrots said to be affected by the presence of the mynas. As these birds are increasing in abundance in the WTR, it is assumed that they are having a negative impact here as well. Since the species' preferred habitat is cleared areas and human settlements it would be expected that any impact of mynas will be restricted to these areas. This, and experience elsewhere in Australia, suggests that, in the WTR, the more open eucalypt woodlands may be the natural ecosystems most at risk from these birds. However as urban and peri-urban developments expand, as is happening throughout the WTR, there is the potential for these birds to increase in abundance and potential impact.

Actions and Outcomes

The pest status of common mynas is not regarded as serious enough to warrant formal management strategies at a national, state or regional scale. However local government areas in conjunction with community groups have developed their own strategies for controlling the birds on a localised scale.

Local

No research has been conducted on the impact of common mynas in the WTR. A joint study between the Australian National University (ANU), the Australian Rainforest Foundation (ARF), CCC, Cairns Water and the community group, Birding Cairns, is currently underway to determine the feasibility of constructing a mobile synthetic roost to trap large numbers of roosting flocks of myna birds. Comparative studies of roosting behaviour are to be made between wild roosts and under controlled conditions in large outdoor aviaries in wet (breeding) and dry (non-breeding) seasons, to determine roosting preferences. Study sites are located in Cairns and Canberra. The final steps in the process will be to field-test prototype roost traps. The joint study in Cairns has just completed the breeding season data collection and is proceeding on the non-breeding season data collection (J. Allen, ARF pers. comm.).

The Tweed and Byron LGAs of northern NSW, along with the local organisation Wetland Care Australia, landholders and community groups have begun the Common Myna Control Project in response to the birds' recent arrival and establishment of colonies. This project aims to prevent further range expansion in the area. It is based on the successful trapping programs undertaken in Canberra which have lowered numbers of common mynas significantly in localised areas, and involves identifying priority sites (such as threatened species protected areas) for trapping (Wetland Care Australia 2007).

At the ANU, Canberra, traps have been purpose-built for common mynas and a system developed to trap them at feeding areas. Whilst this has been successful at a localised scale, at a larger scale and for long term management, it has been recommended that trapping be used in conjunction with other methods such as habitat restoration to favour native birds and limiting the mynas' access to food sources such as pet and livestock food (Tidemann 2004).

Red Fox (*Vulpes vulpes*)

The European red fox is Australia's most important introduced predator since it has been implicated in the decline and extinction of many ground-dwelling native mammals on mainland Australia and has been associated with and responsible for loss of livestock. Its ability to survive in a range of environments, high reproductive success and its wide ranging diet of small rodents, rabbits, carrion of sheep and kangaroos, fruit and insects, have contributed to its success in Australia (Saunders et al. 1995, Short et al. 2002). The fox was first reported in Queensland 1907 (Lapidge et al. 2004-present) and is widespread across most of Australia, surviving within many different habitats including urban, alpine and arid areas (DEH 2006). Its distribution and abundance are thought to have increased in the past ten years (Agtrans Research and Dawson 2005) and the estimated combined environmental and agricultural cost of foxes Australia-wide is $227 million per year (Lapidge et al. 2004-present). Foxes have played a major role in the decline of a number of species including ground-nesting birds, small to medium-sized mammals and reptiles (DEH 2006). They are also potential hosts of endemic and exotic diseases such as rabies (Gentle 2006).

Foxes are rarely seen in north Queensland but they have been sighted as far north as Lakeland Downs, 80 km west of Cooktown and occasionally on properties in the gulf savanna country near Normanton (J. Mitchell, pers. comm.). The fox's main food source is small animals such as mice and rabbits (Strahan 1993, cited in Harrison and Congdon 2002) of between 25 to 5,500 g (Burbidge and McKenzie 1989, cited in Short et al. 2004), but also includes livestock: lambs, goat kids, poultry, insects and fruit (DEH 2006). In forested areas, it prefers native prey (Strahan 1993, cited in Harrison and Congdon 2002) and within the WTR, is currently regarded as a potential threat to the northern bettong (Environment Australia 1999, cited in Harrison and Congdon 2002). If fox populations were to spread throughout the forested areas in the WTR, they would pose a significant threat to many other native species (WTMA 1995, cited in Harrison and Congdon 2002). However, if they behave as those observed by Catling and Burt (1995) and Catling et al. (2000), they will favour more open forests and disturbed or cleared areas rather than rainforest. If foxes increase in abundance and in distribution throughout agricultural areas of the WTR, e.g., the Atherton Tablelands, there is an increased likelihood that they will predate on native ground-dwelling species, particularly at the interface between forests, forest fragments and farmland.

Actions and Outcomes

National

Predation by the European red fox is listed as a key threatening process under the Commonwealth *EPBC Act 1999*. A Threat Abatement Plan for Predation by the European Red Fox was released in 2006 (DEH 2006a). This TAP provides a framework that enables the best use of the available resources for fox management. The plan is largely the basis for guiding the federal Department of the Environment and Water Resources's expenditure on control-technique research and on-ground management in high conservation areas (Hart 2005, cited in Gentle 2006). Thus, the Australian Government is working with the states and territories to deal with this national problem (Environment Australia 1999, cited in Gentle 2006).

Control measures rely heavily on conventional techniques such as shooting, poisoning and fencing. Whereas traditional methods of shooting and bounty-killing rarely have been effective in reducing impacts, fencing and broad-scale control with poison baits containing 1080 have been successful in WA. Similar control activities have occurred in eastern Australia (DEH 2006a). The Invasive Animals CRC (2006) is developing new tools and strategies including attractants, lures and a new toxin that may be more species-specific and humane than traditional poisons. It is also investigating an immunocontraceptive to control foxes which limits their reproduction. Foxes have been observed to be less common where dingoes are present. Therefore researchers are looking at the interactions between foxes, dingoes and feral cats, the results of which could help in integrating fox and feral cat control (Robley et al. 2004, DEH 2006a).

State

The fox is a Class 2 declared pest animal in Queensland, is deemed to be established in Queensland and has, or could have, a substantial adverse economic, environmental or social impact (DNRW 2007g). The management of Class 2 pests involves coordinated control programs led by local government, community or landowners. Further, landowners must take reasonable steps to keep their land free of Class 2 pests (DNRW 2007g). The DNRW aims to minimise the environmental, economic and social impact of foxes in Queensland by promoting regional or community-based control programs, developed and coordinated in areas of significant impact (Gentle 2006). The main strategy used to reduce fox damage in Queensland is 1080 baits. Within agricultural and pastoral areas, strychnine baits are also used in areas close to human habitation and exclusion fencing is sometimes used in conservation lands. Within urban areas, trapping is employed (Gentle 2006).

There are few replicated studies demonstrating the impact of fox predation on Queensland's agricultural enterprises and environment, however, anecdotal evidence suggests that foxes are responsible for significant economic and environmental impact within the state (Gentle 2006). The 2005 distribution assessment indicated that foxes occur throughout southern and central Queensland, but they are absent in the northern areas of Queensland. Their absence in the northern areas may reflect the assumption that foxes do not favour humid tropical regions (Jarman 1986, Saunders et al. 1995, cited in Gentle 2006), or it may simply be that they haven't reached so far north in any great numbers, which would support Coman (1983, cited in Gentle 2006) who states that food supply and adequate shelter are greater determinants of fox distribution than any particular habitat. However comparisons between DNRW's 1981 and 2005 distribution surveys suggest that foxes have not spread any further north during that period (Gentle 2006).

Regional

Nonetheless, the fox is identified as the principal terrestrial 'sleeper' species of concern within the WTR with moderate current impacts but substantial future potential (Harrison and Congdon 2002). It is suggested that the fox's relatively low current impact in the WTR is due only to its present limited distribution within the Atherton and Kirrama-Hinchinbrook provinces (North Queensland Joint Board 1997, Earthworks 2001, both cited in Harrison and Congdon 2002). The distribution of rabbits may also be important in determining the northern boundary of fox distribution in Queensland (Gentle 2006). Evidence from the Atherton Tablelands indicates that rabbits may be colonising new areas (P. Davis, pers. comm.) and given that in the past, fox distribution appears to closely follow that of the rabbit and there is some concern that this may assist foxes in colonising these areas. These concerns are considerable given the number of other susceptible, native prey such as the endangered northern bettong, *Bettongia tropica*, present in these areas (Gentle 2006).

As with dingoes, foxes may currently contribute significantly to rabbit control along the edges of the bioregion (Environment Australia 1999, cited in Harrison and Congdon 2002). It is therefore recognised that the impact of fox control on other pest species needs to be considered in any major control program. Fox risk assessments in the WTR would be aided by detailed information on current distributions, including absence data, and native species interactions (Harrison and Congdon 2002).

Although there have been no studies to quantify the environmental impact of foxes in the WTR, they appear to be in low densities at present. If their potential threat is taken considered, and appropriate management control actions, as well as surveillance and monitoring are undertaken, it is possible that their numbers can be controlled in order to minimise their impact.

Local

Local government area pest management plans (LGAPMPs) assist DNRMW in identifying areas where foxes are perceived to be causing significant impacts and thus undertake control strategies to deal with them (Gentle 2006). Within the regional shires, foxes are noted within the LGAPMPs of the Cardwell, Eacham and Johnstone Shires. Within the Cardwell and Johnstone Shires, the fox is recognised as a state-declared animal, but is regarded as unlikely to become established due to the climatic conditions and thus it is assigned a low priority. Actions include annual review of its pest status, constant surveillance and community awareness of its potential to cause environmental damage (Cardwell Shire Council 2002). The Johnstone Shire Council aims to eradicate foxes from the Shire (Johnstone Shire Council 2002). Within Eacham Shire, the fox is not reported to be a pest, but Council will offer assistance to control the animal where possible, by trapping and fencing (Eacham Shire Council 2005).

Participation in coordinated baiting campaigns for wild dogs and foxes is the most common strategy for the management of foxes at the property level. In situations where this is not appropriate, other suitable control techniques may be available. These fox control techniques can feed into property management plans, which are generally prepared by landowners for their private use (Gentle 2006).

Synthesis of Management Actions for Invasive Terrestrial Vertebrates

This section assesses the outcomes of the management actions taken to address the priority lists and aims to identify why certain actions were successful and why others failed (in general terms across all invasive species). Specifically it looks at a range of factors such as at what stage of the invasion cycle action was taken and the correlation between this and the degree of success achieved.

A review of management actions implemented in Australia between 1994 and 2004 indicated that, in general, current management strategies for vertebrate pests have not been effective because the distributions and abundances of cane toads, feral pigs, foxes and deer have increased (Agtrans Research and Dawson 2005). This review also determined that more resources have been available for the control of pests that affect or have the potential to affect production industries, due to the greater economic importance of these industries than native ecosystems. In comparison, the detection, surveillance, management and research of species that impact on the environment, human health or social infrastructure such as waterways, are poorly resourced and lack the skills base to deal with these issues (Agtrans Research and Dawson 2005). Other reasons for poor responses or control include the absence of a nationally coordinated approach to controlling vertebrate pests, non-uniform legislation across jurisdictions and lack of enforcement of compliance.

The general consensus of those who are responsible for managing invasive species is that the most effective and cost-efficient strategy to control them is to take action early in the invasive process, before the species become established. For example, cane toads have been resident in the WTR for decades and are so widespread that they are now past the point where total eradication is feasible, apart from efforts in localised areas. Feral pigs are also widespread and well established in the WTR, with limited effective controls available, so that total eradication is probably not feasible.

However, early intervention in the invasive process may be complex due to issues with determining whose responsibility or jurisdiction it is to deal with a particular species (e.g. feral deer, cats, dogs, fox and other sleeper species in the WTR). This is exacerbated by the lack of information actually quantifying their impact on native wildlife and plants and the difficulty in addressing social and cultural issues. However, the lack of ecological knowledge available may not be a sufficient reason to not control a potential invasive species. In the case of deer, the most effective option would be to take management action whilst the species is in its early stages of invasion, rather than to wait for detailed knowledge of their ecology and impact in the rainforest. By taking early action to prevent further spread of invasives, some early stage infestations can be controlled (Simberloff 2003).

In the past and in some present instances, evaluation of the effectiveness of control or of eradication programs has been overlooked, possibly due to inadequate allocation of time and resources and poor planning or an assumption that the effectiveness of control will be self evident (Agtrans Research and Dawson 2005, Reid 2006). However methods of assessment of the success of management actions have been developed and are increasingly incorporated into management strategies. The inclusion of science-based performance criteria in a control program is necessary to enable evaluation of how effective the program has been. Without the evaluation, it is impossible to know if the cost and effort has been worthwhile.

A review of cane toad research and management by the National Cane Toad Taskforce (Taylor and Edwards 2005) stated that 'management decisions and funding for research should, if possible, be guided by a cost-benefit analysis'. This is not unique to the cane toad problem but applies to all issues of invasive species management and research. One of the problems encountered with this is that for environmental pests, it is difficult to translate environmental costs into monetary value. Taylor and Edwards (2005) suggest that this problem can be overcome, 'by estimating the potential benefits of a particular management action, applying a probability factor of success and then calculating the cost of that action'… it is then possible to 'rank the different potential projects and choose those with the greatest chance of success'. This includes 'taking no action' as an option. However these authors acknowledge that social and political pressures can affect this approach. For example, although the environmental effects of cane toads are poorly quantified, there is strong social and political pressure to address their control. The situation may be similar for feral pigs in the WTR.

In the WTR specifically, management of invasive vertebrate species has tended to focus on local areas and on short time-frames. The outcomes of such approaches have invariably been measured in terms of animals culled, e.g. 15,000 pigs removed during the community pig trapping program but the local-scale and short-term nature of these activities mean that benefits may be quickly lost through recruitment and dispersal into the control area. Evaluation in this way may also be misleading since the amount of environmental damage caused is not necessarily related to population density (Mitchell and Dorney 2002, Olsen et al. 2006). The main barriers to effective feral pig control in the WTR, acknowledging that pigs have been established in the region over a long period of time, include the widely distributed pig population, their high degree of mobility, legislative difficulties, enormous costs involved, and remoteness of a large part of the WHA. The control that has been undertaken, i.e. trapping on the fringes of the WTWHA and dogging within crops has been effective at the property scale but not so over the broad scale (J. Mitchell, pers. comm.).

Potential Future Threats and Capacity to Meet Them

The MTSRF workshop held last year was aimed at identifying future threats to the WTR and the following issues were considered to be important:

- Insufficient risk assessment of intentionally introduced exotic species (birds, fish, reptiles) and their potential to bring in new diseases to Australia.
- The pathways of introduction of exotic species such as frogs in imported bananas and vertebrate pests brought in on international vessels that make landfall without passing through quarantine or that arrive in air or ship cargo.
- Early detection of sleeper species that are relatively unknown entities at present. Their early detection and identification being complicated by a lack of scientific knowledge about their distribution, density and impact. Thus, our ability to define when they have achieved invasive pest status and to identify the subsequent management response is limited.

- The effects of climate change and how it could affect the distribution of existing and future pest species and current biocontrol agents in the region, ecosystem responses, land use management practices and changes in peoples' attitudes toward invasive species.
- Responsible pet ownership of cats, dogs, exotic birds and fishes and social attitudes toward invasive pests including agricultural and domestic species, and species associated with recreational activities such as bait fish have been identified as issues that could become significant in the future. A lack of awareness of the severity of environmental impacts caused by these species and relating it to peoples' behaviour may be a barrier to managing these issues. For example, 'assisted dispersal' or translocation of species such as deer by people who want to create their own herds for hunting (Moriarty 2004, cited in Jesser 2005) will continue because the problem is not fully understood and there is no current legislation to stop it and no mechanism to enforce compliance.

Agtrans Research and Dawson (2005) report that in the three years to 2005, a potentially serious pest, the asian black spined toad (*Bufo melanostictus*) was detected and intercepted 12 times at the Cairns port (Keenan, pers. comm.). Surveillance and interception such as this and monitoring at the border by the North Australian Quarantine Strategy (NAQS), provide early warning and prevention (if possible) of new pests, disease and weed threats entering northern Australia. The NAQS undertakes surveys within 20 km of the coast of northern Australia from Broome to Cairns and in the Torres Strait Islands, East Timor, Indonesia and Papua New Guinea (PNG). Survey frequency is determined by perceived threats to the individual risk areas within the NAQS zone, e.g. inhabited Torres Strait islands are considered high risk due to their proximity to PNG, whilst the southern coast line of Gulf of Carpentaria is considered to be the lowest risk (Waterhouse 2003). AQIS and NAQS, combined with a high level of community awareness are and will continue to be the main methods to detect exotic species brought deliberately or accidentally into Australia. Since the outbreak of foot-and-mouth disease in the UK in 2001, border controls have been strengthened, quarantine procedures have been reviewed and improved and the range of detection technologies have increased, resulting in increased efficiency in quarantine operations. However in general, surveillance for pests that do not have a potential agricultural impact has been reported to be weaker and there is no national alert list for potential environmental pests (Agtrans Research and Dawson 2005).

Importation of exotic animal species into Australia is controlled by DAFF under the *Quarantine Act 1908* and by DEH under the *EPBC Act 1999*, but once the animals are in Australia, trade and keeping them comes under state and territory legislative control. The animal species can only be imported if they appear on the live import list under the *EPBC Act*. If there is an application to be added to the list, then the animal species must undergo an environmental, disease and pest risk assessment. The Vertebrate Pest Control (VPC) advises governments on issues relating to the import of exotic species and has guidelines for importing, moving and keeping exotic vertebrates in Australia. These guidelines are based on the risk assessment (RA) process outlined by Bomford (2003) that assesses the likelihood of a new species becoming established in the wild, taking into account climate matching and its history of invasiveness elsewhere; the ease with which it can be eradicated and its pest potential. The exotic species is then assigned to a threat category of either extreme, serious, moderate or low. According to Bomford (2006) there are over 200 species of captive exotic birds already in Australia and, of these, only a small number have been assessed for their invasiveness. Assessments of all the exotic bird species and animals are required and the highest priority given to those species that are regarded as pests in their overseas range (Bomford 2003, 2006). Risk assessments have been criticised for not being independent since some aspects require input from specialists in the field, who may also have a vested interest in the outcome of the assessment (BRS 2003, cited in Agtrans Research and

Dawson 2005), however at present there are no arrangements in place to enable an assessment to be undertaken by an independent body.

Synthesis of Research Contributions to Management of Invasive Terrestrial Vertebrates

This section reviews how research has benefited the management of invasive species in the WTR for each species discussed in the sections above. It assesses the strengths and weaknesses of past and current research.

The development of target or species-specific pig baits and baits that are suited to rainforest conditions are major issues that are yet to be addressed by researchers, e.g. failure of PIGOUT bait - suited for dry country but not the WTR (Cowled et al. 2006). The lack of specificity of baits is a problem for control of any large vertebrate pest in the WTR, e.g. deer, dogs. It has been shown again and again that there are currently no control or trapping methods that are effective in significantly reducing the numbers of feral pigs in the WTR. The current on-ground control techniques such as trapping, hunting with dogs and shooting are ineffective in terms of broad scale control, but may be beneficial on a property basis (J. Mitchell, pers. comm.).

Whilst developing a target-specific bait for pigs is useful (Cowled et al. 2006), research which focuses on understanding pig behaviour, quantifying their environmental, economic and social impact, spatial and temporal movements and population dynamics enables more strategic and integrated management to be taken. Studies by Mitchell and Mayer (1997) and Mitchell et al. (2006a, submitted) have determined that pigs dig in specific microhabitats at the start of the dry season when there is still moisture in the soil, that their home ranges are not as large as first thought and that their diggings may affect rainforest seedling survival and consequently forest regeneration. An economic assessment of feral pig impacts determined that they cause greater damage to cane farms than banana farms and that trapping by landowners was the most cost-effective method of control (Mitchell and Dorney 2002).

Similarly, the cane toad is still widespread and has been present for decades. Research continues to search for a long-term control in the form of some natural or genetically modified biocontrol agent or pathogen. Short term control measures are centred on improving trap designs and developing strategies to prevent the spread of the toads to new areas. Early cane toad research was focussed on finding a biocontrol agent and it has only been since 1993 that research included the ecological impacts of toads on native fauna to any great extent (Tyler 2006). Thus, although the toads have been here since 1935, there have been no long term (at least 10 years) studies of their impacts. Interestingly, observational studies may aid in more effective short term control, e.g., observing that toads tend to avoid dense vegetation and they require access to water, thus manipulation of habitat may play a greater role in toad management. The dispersal of cane toads to the Northern Territory has provided a unique opportunity to study invasion dynamics at the invasion front (Philips and Shine 2004, Brown et al. 2006, Shine et al. 2006) and study ecological impacts on predators and other native fauna, providing insights into evolution, adaptation, conservation and the dynamics of invasion events.

Feral deer have been shown to become invasive pests in ecosystems in New Zealand (Caughley 1983, Yerex 2001, cited in Jesser 2005), New Guinea (Chatterton 1996, cited in Jesser 2005) and in the Royal National Park, NSW (Keith and Pellow 2005). At present they are still in low enough numbers to be eradicated or contained, if action is taken now. In this instance, detailed life history data may be secondary to effective and early control measures. The major barriers to this problem appear to be complexities in legislation, confusion as to which (government) agency is responsible for their control, lack of political will and misguided public sympathies for the animals.

Failing control in this early phase, once deer have increased in high enough numbers to warrant eradication, the range of control measures most practical for the WTR appear to be a combination of trapping, hunting with dogs and ground shooting (Jesser 2005). Modelling possible habitat would also be helpful. Issues with these methods include the possibility of dispersing the animals further into the rainforest and how to deal with trap-shy animals. According to Fraser et al. (2003) the use of 1080 poison is not effective when population density is low and there is a plentiful food supply. The requirement of high dosages of 1080 to kill deer creates the potential for many other non-target species to also be killed, therefore this method is opposed by the RSPCA and probably would have little public support (Jesser 2005). Non-lethal methods of control such as chemical repellents on specific plants, strobe lighting, gas-powered scare guns, fencing and guard dogs have been used in the US, but are impractical, expensive, ineffective in the WTR environment and only address movement of deer.

Across Queensland, and particullarly in the agricultural areas of western and southern Queensland where wild dog impacts on livestock are significant, there has been a move away from reactive approaches towards more strategic approaches in wild dog management. This has meant aiming to minimise the impacts of dogs rather than outright killing them. This strategic approach involves: defining the problem, developing and implementing a management plan, and monitoring and evaluating progress and outcomes. For example, large coordinated baiting programs are being implemented which are more efficient and cost-effective and cover a larger area, they are being maintained for longer to deal with other wild dogs moving into areas where wild dogs have been removed and livestock losses are being monitored.

Since little is known about the cat, dog, fox, common myna and deer in the WTR, what is known about their impacts and management is based on research undertaken in other parts of Australia and overseas. Thus, its relevance to the WTR is still to be determined. This need not imply that nothing should be done until more is known. Aspects of invasives' ecology, such as their ability to adapt to a range of habitats and their fecundity, will contribute toward an overall picture of their potential impacts as an invasive pest to the region, and allow some measure of management to be undertaken as a precautionary action.

Research Needs

Considering species that have not been well controlled, e.g. feral pig in the WTR, it may be timely to undertake cost-benefit (including environmental and social costs) or decision-making analyses (Sposito et al. 2002). An analytical hierarchical process (AHP) considers all options and possible outcomes and the costs of control are weighed against effort of control to maximise all benefits. This process is a transparent one and can aid in more objective and informed decision-making, providing direction for where future management actions should be focussed. This process was used by Maguire and Albright (2005) to determine why land managers in the USA have been overly cautious or risk-averse in relation to fire management decisions for public- and private-managed forests. It involved considering all management options and the disadvantages and advantages of the consequences of each one. Although it was used for fire management in this instance, the process can be adapted to issues relating to management of invasive species. For example, it has been used in Victoria for weed and natural resource management risk assessment and prioritisation (Sposito et al. 2002, Weiss et al. 2006).

Feral pigs are the terrestrial vertebrate species most consistently identified as a priority in the WTR. They remain a significant problem in the Wet Tropics due to the lack of effective control methods suited to rainforest conditions. Despite some investment on the ecology and life history of feral pigs and development of various control methods, and larger funds used for current management strategies, feral pig numbers have not been reduced significantly in the WTR.

All four of the species listed as major vertebrate pest species by Harrison and Congdon (2002) (pig, cat, cane toad and dingo/dog) are species that have been present in the WTR and Australia for periods ranging from decades for the cane toad (Lever 2001) to *ca.* 4,000 years for the dingo (Corbett 1995). These species appear to have reached the limit of their distribution in the region and are now an established component of local communities. There is no doubt that these species continue to have an impact on the communities in which they reside through habitat disturbance or predation and that their eradication would result in a 'bounce back' of affected species or communities. However, there is little evidence to suggest that, under many circumstances, these species are exerting a continuing downward pressure on the populations or communities with which they interact. Instead most populations and communities may have reached a dynamic equilibrium with them. Their long establishment period, the absence of any firm, scientific indication of an ongoing impact, their establishment elsewhere in the region, the failure to gain strong support for their control, the absence of approaches that would allow regional scale controls, all combine to suggest that specific research into their control may not be warranted in the context of MTSRF. However it must also be acknowledged that this lack of 'evidence' is because there have been virtually no scientific studies, particularly in the WTR, to quantify the actual environmental impacts by these animals on native fauna and such studies are required to determine their true pest status.

The exception to this is feral pigs. Within certain environments, e.g. riparian and coastal zones, pigs are known to cause significant physical damage and they can be major predators of some species, e.g. turtles (Fordham et al. 2006). Aside from direct impacts on biodiversity, pigs are perceived to have a significant impact on riparian habitats and water quality, cause damage to crops, particularly bananas and sugar cane, and, are known to act as reservoirs for diseases of agriculture (e.g. foot and mouth disease) and humans (e.g. Japanese encephalitis). These factors combined translate into a constant public pressure for pig control particularly at the boundary between the World Heritage Area and agricultural areas and in the context of significant habitats, e.g. riparian and turtle nesting areas. While pigs are not currently reservoirs of significant diseases this is a major concern particularly with the WTR being so close to major pathways for the introduction of diseases. These considerations suggest that a primary concern for invasive research is the development of pig control methods that can effectively minimise pig numbers and movement in key areas to prevent damage or limit spread or exposure to disease. This would require a scientific understanding of how control activities affect the population structure and redistribution of the animals and would incorporate social, economic and institutional arrangements for the control and ecology of feral pigs in the WTR.

Suggestions for Feral Pigs

- Control and kill technologies.
- Development of a WTR specific pig baiting and associated research that minimise impacts on non-target species.
- Biological control strategies.
- Fertility control.
- Species-specific bait delivery.
- "Innovative" kill technologies.
- Development of appropriate pig population monitoring methodologies for rainforest environments.

- Field surveys.
- Genetic based approaches.
- Impact assessment methods, including environmental, economic and other costs.
- Impact of feral pigs on specific (rare and endangered) species in the WTR, e.g. wild banana, *Musa* spp.
- Population dynamics, population spatial distribution and individual movement.
- Development of an integrated and strategic approach to pig management that incorporates an understanding of the interaction between the spatial distribution of pig populations and control activities on the one hand and control effort and social, economic and institution arrangements on the other.
- Cost benefit analysis of pig control (economic, social and environmental), Analytical Hierarchical Decision Trees.

Impacts of Cane Toads on Biodiversity

- Investigate the status of populations of affected species in areas in WTR that have been exposed to cane toads for a long period. Priority groups would be predators including vertebrates such as goannas, frog-eating snakes and quolls but also other anurans and invertebrates, and communities upon which cane toads predate, e.g. arthropod communities.

Suggestions for Wild Dog and Feral or Stray Domestic Cat Research

- Better definition of the environmental impacts of wild dogs and cats in the WTR.
- The effects of wild dog control on the abundance of macropods and other native wildlife, e.g. the Mareeba rock wallaby (*Petrogale mareeba*).
- The interactions between predation by wild dogs or cats and the conservation status of key species.
- The interaction between distributions and abundances of wild dogs and feral cats, foxes and quolls.
- Urban areas as sources and impact foci – feedback into planning processes.

Deer

- Potential distribution within WTR.
- Potential ecological impacts.
- Ecology and distribution of current populations.

General Vertebrate Pest Research Suggestions

- Determine the ongoing impacts of key invasive species in the WTR – are they still causing declines in relevant indices or have native communities accommodated them?
- Evaluation of potential distribution (geographic and habitat type), impacts and most effective control measures of future WTR pests, including: foxes, deer, myna, spotted turtle dove, cats, dogs.
- Development of decision support systems and analysis tools for assessment of management options.

Terrestrial Weeds

Priority Listings

As with other invasive species in Australia, weeds that reduce economic output of the primary industries have received the majority of attention in terms of resource allocation and research. Very little attention has been paid to environmental weeds that affect biodiversity and natural resources or those that cause health problems such as asthma and dermatitis. The National Weed Strategy defines a weed as 'a plant that has or has the potential to have, a detrimental effect economic, social or conservation values' (C of A 1999). It includes exotic introduced plants and pasture grasses that have escaped beyond the garden or farm into areas of natural vegetation but also includes native plants that grow beyond their natural range.

Introduction pathways for plants are complex. Some plants are introduced accidentally, such as contaminants in seed, on motor vehicles or equipment brought in from other areas. Many, however, are introduced deliberately, e.g. as agricultural or nursery introductions. Potentially some species could also be introduced by migrant animal species (Stansbury 2003) and even by ocean currents, though there is no evidence to suggest that this has occurred in the context of the WTR.

A review by Agtrans Research and Dawson (2005) states that whilst there are no definite trends on the containment of individual weeds across Australia, there is an overall impression that the abundance and distribution of weeds is increasing. Grice and Setter (2003) report that ca. 10% of the total flora (terrestrial and aquatic) in the WTR are exotic plant species that have become naturalised, representing a whole range of life forms from forbs to vines to trees. Weeds successfully compete for soil nutrients, light and water against native plant species in WTR ecosystems. This can lead to the exclusion of native species from recruitment opportunities in some cases, e.g. pond apple, *Annona glabra*, resulting in a sharp reduction in local species richness with the potential, should all available habitat be invaded, for loss of native species. This may also affect native animals through the reduction of food sources, shelter and habitat loss. In other circumstances the invasive species becomes a component of the community with little apparent impact (Murphy et al. 2007, in prep).

In 2001, a priority list for weed species requiring research in the wet and dry tropics of north Queensland was developed by Bebawi et al. (2001) based on social, cultural, economic and environmental criteria. It was developed in response to the increasing number of exotic plants species threatening the WTR and the need to prioritise research projects. Thirty-one of 53 weed species (both terrestrial and aquatic weeds) from the WTR were identified as research priorities including five Weeds of National Significance (WoNS). Two hundred and forty-six weed species derived from pest management plans (PMP) of 47 local government agencies north of the Tropic of Capricorn were the initial basis of the project. From this, 50 weed species were short-listed for evaluation and impact scoring. Subsequent assessment by stakeholders resulted in three more species being added, making a total of 53 weed species. The short-list of weeds was divided into Wet and Dry Tropics. This report is only concerned with the 31 weed species listed for the Wet Tropics (Table 3), an area defined as receiving 1600-3400 mm rain year^{-1}, although it is acknowledged that some weeds are found in both the wet and dry areas and also have different levels of importance according to their abundance in each place.

A review of past prioritisation programs was undertaken and the Multiple Objective Decision Support System (MODSS) was selected as the most suitable tool for ranking the species. This system was used by Wilson and Panetta (1998, cited in Bebawi et al. 2001) to determine research priorities for southern Queensland weeds. It requires expert knowledge or professional opinions and therefore is a highly interactive system. A panel of weed experts ranked the 53 weed species based on two main criteria: impact and research already undertaken. To increase the sensitivity of the weed assessment, these criteria were further qualified by:

- **Impact:**
  - economic, social/cultural and environmental (current and potential).
- **Research:**
  - control (herbicide, fire, mechanical, biocontrol).
  - ecological (reproduction).
  - social (socio-economic).

Each weed was given a best estimate score on the impact criterion by each panel member, but the final score was achieved by consensus. In order to have a measure of objectivity in the scoring, the impact and research criteria scores were guided by general weed knowledge and a prepared list of specific considerations related to each criterion. For example, for the environmental impact criterion, considerations were given to a range of aspects such as net change in biodiversity, ecological processes, allelopathic effects, ability to create a fire hazard in natural ecosystems and indigenous and non-indigenous heritage. Similarly for the biocontrol research criterion considerations included overseas surveys of pathogens and insects, and surveys of Queensland pathogens and insects. The scores for the third order criteria such as current and potential impacts and research of various methods of control were based on a combination of published literature and expert knowledge.

Once the scoring was done, scores given by the weed experts were checked for credibility and validity and those given by stakeholders in the PMPs were cross-checked. The results indicated that the impact priority ratings from both sources were valid, credible and compatible. Four different 'what if' scenarios with varying degrees of importance allocated to the base criteria were then run in MODSS for the weeds. This provided an objective assessment of how the ranking for each weed would be affected in each of the different scenarios.

The scenarios were:

- Economic impact, with potential impact being greater than (>) current impact;
- Environmental impact, with potential impact > current impact;
- Economic impact > environmental impact > social and cultural impact, with potential impact > current impact; and
- Impact (economic > environmental > social and cultural with potential > current) > research ((control: herbicide = mechanical = fire) > biocontrol)) > ecological > socio-economic.

Scenario 4 was deemed to be the most useful scenario to use because it acknowledged that previous research undertaken by DNR had been driven by weed impact; it also added value to the prioritisation process by including research criteria in the assessment process. The resultant weed research priority list (Table 3) shows the weed species, ranked in descending order of priority, whose overall impacts were determined to be greater than the information known about them [thus research is required]. After the weeds were prioritised by MODSS, the panel of weed experts met again and each weed was assessed to determine whether it was a 'search and destroy' case or not and whether it was a candidate for biocontrol research. If it was a weed that required eradication, then research was not considered necessary unless development of chemical control was required for its eradication. Results indicated that 23 % of the WTR weeds were in the 'search and destroy' category and therefore would not require allocation of resources for research into their management and control, and that 37 % of the weeds required a biocontrol program. Research gaps for each weed were then identified and subject to external review. This whole process provided a research profile for each of the weeds and a breakdown of percent research requirement that could be related to the allocation of research dollars for individual aspects of research, e.g. how many research dollars could be spent on biocontrol or ecological research (Bebawi et al. 2001).

Werren (2001) developed and undertook an environmental weed risk assessment (WRA) and a priority ranking system to aid allocation of scarce resources for weed management in the WTR. The process comprised four main stages:

- Making a list of existing weeds, potential sleeper weeds, and plants not currently found in the WTR but which are known environmental weeds in similar environments elsewhere;
- Prioritisation of potential environmental threat, based on biogeographic, historical, biological and ecological criteria thus highlighting aspects of weed invasion peculiar to plants, communities and ecosystems within the WTR. Socio-economic impacts such as costs and feasibility of control were deliberately left out as they were regarded as secondary to inherent invasiveness potential, and would be considered after environmental risk had been determined;
- Evaluation of plant species that have become naturalised in the WTR; and
- Consideration of appropriate management actions, including prevention of weed entry, importance of early intervention, using ecologically integrated weed management and control or containment of existing weeds.

Table 3. Priority list of WTR weeds that require research, ranked in descending order of priority (Bebawi et al. 2001). (*) = Weed of National Significance.

Scientific Name	**Common Name**
Mikania micrantha	Mile-a-minute
Chromolaena odorata	Siam weed
Mimosa diplotricha	Giant sensitive plant
Eupatorium catarium	Praxelis
Thunbergia spp.	Thunbergia
Miconia calvescens	Miconia
Annona glabra *	Pond apple
Alternanthera philoxeroides *	Alligator weed
Hymenachne amplexicaulis *	Hymenachne
Andropogon gayanus	Gamba grass
*Cabomba caroliniana**	Cabomba
Stachytarpheta spp.	Snakeweed
Harungana madagascariensis	Harungana
Senna obtusifolia	Sicklepod
Elephantopus mollis	Tobacco weed
Cyperus aromaticus	Navua sedge
Psidium guajava	Guava

Scientific Name	Common Name
Leucaena leucocephala	Leucaena
Brachiaria mutica	Para grass
Spathodea campanulata	African tulip tree
Hyptis spp.	Knobweed
Rottboellia cochinchinensis	Itch grass
Euphorbia heterophylla	Milkweed
Allamanda cathartica	Yellow allamanda
Turbina corymbosa	Turbine vine
Sphagneticola trilobata	Singapore daisy
Tithonia diversifolia	Japanese sunflower
Sansevieria trifasciata	Mother-in-law's tongue
Eichhornia crassipes	Water hyacinth
Pistia stratiotes	Water lettuce
Salvinia molesta *	Salvinia

The result of the priority risk assessment was a preliminary ranking of 57 WTR weed species (Table 4) from a total of 504 exotic plants that have become established in the WTR, including two WoNS. This total of 504 exotic plants in the WTR was derived from the Queensland Herbarium's HERBRECS database from November 2000, and therefore is probably an underestimate of the real number of introduced plants currently in the WTR. At least 210 exotic weeds have been collected in WTR rainforests alone, to date (A. Ford, pers. comm.). The ranked species comprised 50 terrestrial weeds and seven aquatic weed species, which are a subset of the major weeds already identified by 'a range of interest groups' (Werren 2001).

According to Werren (2001) weed management is often limited by lack of reliable information about the distribution and ecology of the weed species. To overcome this problem, it was recommended that:

- Ecological data be collected and WRA of the remaining 448 species that were the basis of the priority list, be undertaken;
- The WRA be subject to a sensitivity test;
- Determinants of and ecology of likely sleeper species be determined;
- Distribution maps of infestations of major weed species, especially high scoring weeds, be prepared to aid strategic control actions;
- Integrated and coordinated weed control be developed which takes into account native species and communities;
- Use of biocontrol on the highest priority weeds and other weeds that have no or few closely related native species be investigated; and
- A secondary assessment that considers the cost and feasibility of weed control and addresses strategic matters associated with weed management be developed.

Table 4. Prioritised terrestrial weed species of concern in the WTR as determined by Werren (2001), in descending order of priority. (*) = Weed of National Significance

Scientific Name	Common Name
Annona glabra *	Pond apple
Leucaena leucocephala	Leucaena
Chromolaena odorata	Siam weed
Sphagneticola trilobata	Singapore daisy
Hymenachne amplexicaulis *	Hymenachne
Miconia calvescens	Miconia
Psidium guajava	Guava
Thunbergia spp.	Thunbergia
Mikania micrantha	Mile-a-minute
Brachiaria mutica	Para grass
Panicum maximum	Guinea grass
Parmentiera aculeata	Cucumber tree
Turbina corymbosa	Turbine vine
Ageratina riparia	Mistflower
Mangifera indica	Mango
Eupatorium catarium	Praxelis
Andropogon gayanus	Gamba Grass
Spathodea campanulata	African Tulip tree
Tithonia diversifolia	Japanese Sunflower
Solanum seaforthianum	Brazilian Nightshade
Azadirachta indica	Neem tree
Harungana madagascariensis	Harungana
Stachytarpheta spp.	Snakeweeds
Senna obtusifolia	Sicklepod
Syngonium podophyllum	

In 2002, a workshop to consider weed research issues in WTR rainforests (Grice and Setter 2003) rather than focusing on specific individual high priority weeds, considered the more general research needs and management approaches. While this workshop accepted the importance of the species in the priority listings of Bebawi et al. (2001) and Werren (2001) it did identify a number of new weed incursions in the early stages of the invasion process, e.g. *Chromolaena odorata* and *Mikania micrantha*, and concluded that these and potential candidate or sleeper species should also be considered high priorities.

In addition to the priority list of feral vertebrate pests in the WTR (see Terrestrial vertebrate priority list section), the Wet Tropics Conservation Strategy (WTCS) also has a prioritised list of environmental weeds that are deemed likely to threaten WH values. The priority rankings are based on the plant's potential to invade, disrupt and transform a variety of WT ecosystems. The list was developed for the purpose of providing some focus for weed control programs within the WTWHA and WTR. It includes species that are in the early stages of invasion in the WTR (Table 5), those that are major weeds in other tropical areas, such as Pacific islands, and have the potential to spread here (candidate species), those that have become established and are already invasive in the WTR and those that are already established in the WTR and which may become problems in the future (sleeper species). To see the full list, refer to the WTCS Strategic Plan (WTMA 2004). The WTCS strategic approach to weeds includes:

- Prevention of new species of invasive weeds being introduced to the WTR;
- Eradication of new and localised outbreaks of environmental weeds;
- Weed eradication priority given to intact areas rather than disturbed areas;
- Weed eradication programs where eradication is feasible and where long term monitoring and rehabilitation are included;
- Provision of identification, reporting and weed control information to land managers and the public; and
- Research of the ecology and management of priority weeds in the WTR.

Table 5. High priority newly emerging environmental weeds, recommended by the WT Conservation Strategy to be eradicated completely in the WTR (WTMA 2004). (*) = WoNS.

Scientific Name	Common Name
Miconia calvescens	Miconia
Clidemia hirta	Clidemia/Koster's curse
Chromolaena odorata	Siam weed
Hiptage benghalensis	Hiptage
Mikania micrantha	Mile-a-minute
Miconia racemosa	Miconia
Alternanthera philoxeroides *	Alligator weed
Brilliantaisia lamium	Brilliantaisia
Ageratina riparia	Mistflower
Limnocharis flava	Limnocharis
Thunbergia laurifolia	White trumpet vine
Phytolacca rivinoides	Venezuelan pokeweed
Coffea arabica, C. liverica	Coffee
Andropogon gayanus	Gamba grass
Echinochloa polystachya	Aleman grass
Castilla elastica	Panama rubber
Flacourtia jangomas	Indian plum
Parmentiera aculeata	Cucumber tree
Manihot glaziovii	Ceara rubber tree

It is interesting that this priority list is different to both lists developed by Bebawi et al. (2001) and Werren (2001). The main difference is that although Bebawi et al. (2001) also considered the impact of the weed species, they were focused on making a list of high impact weeds which require research to enable more effective controls to be developed. Werren (2001) also considered the impact of weed species already established in the WTR, and biogeographic and ecological aspects but length of time of establishment and therefore feasibility of control was not a major consideration. Instead feasibility of control was regarded as the next part of the process to be considered after the weed risk assessment. This priority list reflects the strategy recommended at the Weeds in Tropical Rainforests workshop held by Grice and Setter (2003) to focus on high impact weeds that were newly arrived and where eradication was still feasible.

From a management perspective the high priority weed species have been defined by action on the ground. Thus, the management priorities for the WTR have been those species that are the focus of the Four Tropical Weeds Program (4TWP): Mikania vine (*Mikania micrantha*), miconia (*Miconia* spp.), limnocharis (*Limnocharis flava*), clidemia (*Clidemia hirta*), Siam Weed (*Chromolaena odorata*), pond apple (*Annona glabra*) and agricultural escapes such as the introduced pasture grasses, e.g. hymenachne and Para grass.

Policy Frameworks

National

The Australian Weeds Committee (AWC) is the national body that deals with all weed issues and has recently extended its scope to include environmental weeds. It has compiled a list of Noxious weeds found within Australian states and territories, which is regularly updated. The AWC is also responsible for overseeing the implementation of the National Weeds Strategy (NWS) (C of A 1999). The NWS was first released in 1997, reviewed in 1999 and is currently being revised. It provides the framework to reduce the impact of weeds on the sustainability of Australia's primary industries and natural ecosystems, through the establishment of a number of goals, management actions and outcomes and requires coordinated and cooperative weed management between all levels of government, industry, land holders and managers, community groups and the general public (DEH 2004).

One of the goals of the NWS is to 'reduce the impact of existing weed problems of national significance'. This has been achieved by the development of an assessment procedure to determine and rank weeds of national significance (WoNS) over a range of land uses at the national level, which can be used to prioritise weeds at the State, regional and local levels (DEH 2006b). A WoNS refers to a plant that 'threatens the profitability or sustainability of primary industries, threatens conservation areas or environmental resources of national significance, requires action across states and territories and is a major threat to biodiversity (C of A 2006e).

The National Heritage Trust (NHT) is the major source of federal funding for regional level weed management activities that target WoNS and weeds on the National Environmental Weeds Alert List (NEWAL) and for actions that are aimed at developing strategic integrated approaches to reducing the impact of priority weeds. Additional funding for programs dealing with WoNS is provided by the DAFF and Environment Australia. The federally funded Envirofund provides funding to communities and individuals to undertake conservation and sustainable resource use, including activities that address weed problems (DEH 2004).

State

The Queensland Weeds Strategy 2002-2006, provides a framework for cooperative weed management between government, community, industry and individuals throughout Queensland. It has five main components which are:

- Awareness and education of all stakeholders about weed management issues;
- Assessment of available information so as to make informed weed management decisions;
- Planning, responsibility and resourcing of the strategic weed management actions established by all stakeholders;
- Prevention of the establishment and spread of weeds; and

- Integrated weed management systems are implemented.

The Strategy is aimed at controlling introduced invasive weeds, including agricultural, aquatic and environmental weeds and weeds declared under the *Land Protection (Pest and Stock Route Management) Act 2002*, native woody and aquatic species that have become weedy where they naturally occur and native plants that have been introduced to areas beyond their native range and which have become weedy in the new environment.

Under the Act, weeds may be classified into one of three classes: Class 1 if it is not commonly present or established in Qld and has the potential to cause an adverse economical, environmental or social impact. Class 2 and 3 pests constitute those that have established in Qld and are causing or have the potential to cause serious economic, environmental or social impacts. In deciding whether to declare a plant to be a Class 2 or Class 3 pest, consideration is given to:

- Significance of the plant's impact or potential impact;
- The area affected or likely to be affected by the impact; and
- The extent to which the plant has spread or is likely to spread.

This legislation requires that declared weeds growing on State managed land must be controlled by State government authorities, and that landholders must take reasonable steps to keep their land free of declared weeds by controlling and, if possible, eradicating any outbreaks on their property.

Regional and Local

The Far North Queensland Regional Organisation of Councils's (FNQROC) weed species list in their Regional Pest Management Plan (RPMP) includes species from a variety of sources, including: the NAQS alert list, the WoNS list, the State-declared list, priority species included in individual Council PMPs, those species that threaten the environment or agriculture, those where control is achievable, Class 1 Pests and quarantine weeds (FNQLGPPAC RPMP 2006). A weed prevention strategy is currently being drafted by the group to minimise and prevent the further spread of weeds in FNQ.

The main aim of this RPMP is to identify, record and prevent the establishment or spread of pest plants within the FNQROC area and Hinchinbrook Shire and to meet the obligations set under the *Land Protection (Pest and Stock Route Management) Act 2002.* Weed species are assigned to four classes according to priority of control:

Priority 1 – control feasible within resources available, to be eradicated. Includes State declared Class 1 species.

Priority 2 – medium priority, to be contained and reduced with a long term aim of eventual elimination if possible.

Priority 3 – beyond control, isolated outbreaks to be eliminated, populations reduced and spread suppressed.

Priority 4 – low priority, requiring little effort and relatively minimal resources, can either be low risk invaders or high risk sleepers, their control is to be consistent with the level of Declaration and local adverse impact or both.

At a local level, each local government area is required to develop its own PMP addressing invasive species (weeds) issues. This comprises a list of weed species of concern for that particular area, a description of the species, an outline of who is responsible for its control and the recommended control action to be taken. Under the *Land Protection (Pest and Stock Route Management) Act 2002*, local governments are responsible for the control of declared weeds growing on council managed land and must ensure effective control of declared weeds on freehold and leasehold land, and individual landholders are responsible for control of declared weeds on their land and must comply with any pest control notice served upon them by local government.

The Four Tropical Weeds Program

The Four Tropical Weeds Program (4TWP) began in 2003 for an initial period of five years to June 2007. Its aim is to eradicate miconia (*Miconia calvescens* and *M. racemosa*), mikania vine (*Mikania micrantha*), clidemia (*Clidemia hirta*) and limnocharis (*Limnocharis flava*). The 4TWP has five main components:

- Surveillance;
- Control;
- Research;
- Extension;
- Communication; and
- Evaluation criteria (Table 6).

Table 6. Summary of the main activities associated with the eradication of weeds in the 4TWP.

4TWP Management Components	Associated Activities
Surveillance	Delimiting surveys with control undertaken throughout the year, data recorded and added to the PestInfo program.
Control	Data collection, agreements with landholders, weed seed hygiene protocols, risk assessments for working near infestations and risk reduction measures.
Research	Determination of: best control methods, time for plants to reach maturity, age to reproduction, seedling survival, time required to deplete the seed bank, treatments to reduce seed bank, bird dispersal.
Extension and communication	Information of: where infestations are, weed identification, control and prevention of spread.
Evaluation criteria	Performance criteria for evaluation of effectiveness of eradication.

In 2003, the estimated time frame for eradication of miconia was 20 years, and 10 to 15 years for mikania vine/clidemia/limnocharis. In late 2006 the 4TWP's performance was subject to an external review and it was recommended that the program receive continued funding (Cole and Dodd, unpubl.).

Miconia (*Miconia calvescens* and *M. racemosa*)

Miconia calvescens is a tree that is shade-tolerant and is a prolific seeder. It is regarded as one of the most invasive and damaging weeds in the wet forests of French Polynesia and Hawaii (Csurhes and Edwards 1998). It has the capacity to form dense monocultures that exclude recruitment of native species over large areas, causing habitat loss. These dense stands are characterised by bare soil and barren understorey that decrease water retention, promote landslides and increase silting. In Hawaii the combined economic, infrastructure, water and environmental costs of not controlling *M. calvescens* infestations on the islands of Oahu and Maui are estimated to be ca. $US 7.7 billion, while the various options for control range in the order of tens of millions per year depending on the option chosen (Kaiser et al. 2007). Miconia is a prolific seeder able to colonise undisturbed, disturbed and degraded sites. It was introduced to Australia at the Townsville Botanic Gardens in 1963, prized for its attractive foliage, and was subsequently cultivated by botanic gardens in Melbourne, Sydney, Brisbane and Cairns. Although it was removed from the Cairns botanic gardens in 1996, it has been propagated in the WTR by nurseries and plant collectors, and dispersed by humans and birds. It was declared a Class 1 Weed in 2002. For the purposes of eradication, *M. calvescens* and *M. racemosa* are considered equivalent and are being eradicated simultaneously (AWC 2006). It is estimated that control programs will have to run for ca. 10 years after eradication.

Mikania Vine (*Mikania micrantha*)

Mikania vine is a fast growing perennial vine originally from the neotropics (AWC 2006, Waterhouse 2003). It has been introduced widely in the Asia-Pacific where it has become naturalised and is a serious weed. Mikania forms dense tangled infestations in pastures, plantations and disturbed forests and suppresses underlying vegetation. It propagates both vegetatively from stem fragments and from wind-borne seed that are produced in prodigious quantities. Small infestations of mikania were first detected at Bingil Bay, Mission Beach and Forrest Beach in June 1998 and then at Speewah and Ingham in 2001 (Smith 2002, cited in Waterhouse 2003). The current total known infested area is less than 10 hectares and the species is subject to an eradication campaign managed by DNRMW and Mareeba and Hinchinbrook Shire councils.

Clidemia/ Koster's Curse (*Clidemia hirta*)

Clidemia is another neotropical shrub that has become naturalised and is a serious weed in the Asia-Pacific, particularly in Malaysia, Indonesia, Fiji and Hawaii. It is a shade-tolerant shrub that forms dense stands in forest understoreys, causing loss of habitat and displacement of sub-canopy species (Bingelli 1997). Clidemia fruits prolifically and its seeds are dispersed by birds, feral pigs, floodwaters and humans (Waterhouse 2003). It can survive in a range of environmental conditions, grows rapidly and is able to also take root from detached leaves and stems in rainforests, and resprouts readily when damaged (Bingelli 1997, DeWalt et al. 2004, Smith 1993, Tunison 1991, all cited in Breaden, unpubl.). A small infestation of Clidemia was discovered along an ephemeral stream at Julatten, north Queensland in August 2001 (Smith 2002, Waterhouse 2003) and is believed to have arrived in Australia as contaminant in palm seed (Waterhouse 2001). It is a declared Class 1 weed in Queensland, under the *Land Protection (Pest and Stock Route Management) Act 2002* and therefore eradication is required.

Limnocharis (*Limnocharis flava*)

Limnocharis is an aquatic perennial herb. It roots in muddy substrate, is a prolific seeder and produces many vegetative shoots. Seeds and plantlets are waterborne and are transported by humans as an ornamental or green vegetable (Smith 2002, cited in Waterhouse 2003). It is also possible that seed is spread by waterfowl. Limnocharis forms dense infestations in wetlands, slow-moving streams, shallow lakes and dams and is invasive in the USA, Sri

Lanka, India, and south-east Asia, including Indonesia (Waterhouse 2003). It has the potential to become a problem in environmentally significant RAMSAR listed wetlands, naturally occurring riparian areas, irrigation ditches and aquaculture facilities in tropical Australia. It can also affect human health through its negative impacts on water quality (AWC 2006). Infestations from cultivated plants were first detected in the WTR in 2001, some were also found in several suburban ponds (Waterhouse 2003) and some wild plants have been found in the Mulgrave River near Babinda (the original source remains unidentified).

Siam Weed (*Chromolaena odorata*)

Siam weed is a climbing shrub growing to about 3 m tall in open sites, but when trees are available it scrambles up to a height of 20 m (Setter and Vitelli 2003). It propagates vegetatively from stem and root fragments and produces huge numbers of wind-borne seeds that are spread as contaminants of vehicles, machinery, animals and water (Smith 2002, cited in Waterhouse 2003). Siam weed forms dense stands, invades agricultural land, pastures, woodlands, forest gaps and stream banks and roadsides. By forming dense stands it inhibits regeneration by native species. It is both fire tolerant and fire promoting. Siam weed was first detected by NAQS officers at Bingil Bay, near Mission Beach in 1994. Additional infestations were subsequently found along the Tully River and Echo Creek, and one plant was found at Mt Garnet. Initial surveys suggest that Siam weed had been in Queensland for at least 20 years at the time of its discovery and that it was probably introduced as a contaminant of pasture seed. A nationally funded eradication campaign managed by DNRMW, began in August 1994 and is still underway. The cost of the program between 1994-2002 was approximately $1.4 million. Although eradication has been successful so far, the location of isolated plants and the persistent seed bank remain problematic (Waterhouse and Zeimer 2002, cited in Waterhouse 2003).

Giant Sensitive Plant (*Mimosa diplotricha*)

The Giant sensitive plant *Mimosa diplotricha* is a shrubby or sprawling annual and can also grow as a perennial vine, forming dense clumps up to 2 m high. It has the capacity to climb over and choke out native vegetation and is a declared Class 2 plant. Giant mimosa comes from tropical South America, it invades plantations, tropical pastures, riverbanks, roadsides and non-productive lands and is invasive throughout the Pacific Islands, South East Asia, India, PNG, Mauritius and Nigeria (Waterhouse and Norris 1987, cited in Vitelli et al. 2001, DNRW 2006). Its seeds can remain dormant for up to 50 years and its spiny stems can cause serious injury or the death of animals if they get trapped within its thickets. Giant mimosa was first recorded in north Queensland in the 1920s and although it is not known how it was introduced, it is believed that seeds were brought in as contaminants of imported tropical legume seed stock. Giant mimosa is now widespread throughout tropical Queensland, from Ingham to Cooktown. Heaviest infestations occur in the Johnstone and Cardwell shires and it is also present in the Cook, Douglas, Hinchinbrook, Mareeba and Mulgrave shires within the WTR. The combinations of mechanical and chemical control on a regular basis to prevent seeding have been effective and the success of the psyllid *Heteropsylla spinulosa* as a biocontrol agent has helped control the weed, although eradication is unlikely (DNRW 2006a).

Praexelis (*Eupatorium catarium*/*Praxelis clematidea*)

Waterhouse (2003) describes *E. catarium* as a short-lived perennial herb originating from South America. It was first identified in Australia in 1993/1994 from the Innisfail and Tully areas where it was present for at least ten years, but had been misidentified as ageratum *Ageratum conyzoides.* Praexelis is thought to have been introduced as a contaminant of pasture seeds imported from Brazil and is now spread between Townsville, Mossman and the Atherton Tablelands; small infestations have also been recorded on Cape York Peninsula and on islands in the Torres Strait. Praexelis invades the understorey of relatively undisturbed woodlands, cultivated areas, riparian areas, pastures and roadsides. Its seeds are wind-dispersed and are also spread by vehicles and as contaminants in landscaping materials. The long period of time that praexelis has been resident in the WTR and its wide distribution means that complete eradication is not considered feasible, but containment to prevent further spread is possible in localised areas.

Thunbergia spp.

Three species of the *Thunbergia* genus: *Thunbergia grandiflora*, *T. laurifolia* (blue/white trumpet vines) and *T. alata* (black-eyed susan) present major threats to tropical rainforests in the WTR and monsoon vine thickets across northern Australia. These vines were introduced as garden ornamentals and have escaped from cultivation. They are vigorous climbers that smother large areas of rainforest, in some instances pulling mature trees down by their weight, they also shade out and displace understorey plants. Thunbergias are found growing along watercourses and in tropical lowland rainforest.

Pond Apple (*Annona glabra*)

Pond apple *Annona glabra* is a neotropical tree that was first introduced to Australia in the early 20th century as root stock for its commercially cultivated cousin, the custard apple, *A. squamosa.* Pond apple is a low tree that produces numerous, large fleshy fruits that are consumed by a wide variety of vertebrates, though cassowaries and feral pigs are most likely the dominant dispersers (Westcott et al. in press). The light seeds float extremely well and can tolerate periods of immersion of six months and longer (S. Setter, DNRW, pers comm.). The seeds are often encountered in dense piles at high water and current lines along rivers and beaches of infested drainages in the WTR. In 2003 it was known to cover more than 2000 ha in the WTR. Pond apple forms dense monospecific thickets that can exclude recruitment of native species and it can establish in the absence of disturbance. This means that pond apple is a threat to melaleuca and pandanus wetlands, sedgelands and native mangrove communities, in particular, but can also displace riparian and other wet soil rainforests. Pond apple is actively controlled by Shire Councils where it occurs.

Gamba Grass (*Andropogon gayanus*)

Gamba grass, *Andropogon gayanus,* is a perennial grass that grows to between 1-4 m in height, and forms dense tussocks up to 1 m in diameter, that exclude native grasses. It is a prolific seeder, capable of producing between 15,000 and 244,000 seeds per plant per year, compared to native grass species in habitats it invades, such as black speargrass, *Heteropogon contortus*, which produces 50-6300 seeds m^{-2} (Orr 1998, cited in Csurhes 2005). Gamba grass is native to the tropical and sub-tropical savannas of Africa and is climatically matched to north Queensland. It was introduced to the Northern Territory as a pasture grass where it is now a serious environmental weed. Gamba grass was first recorded in Queensland in 1942 near Rockhampton and has since become naturalised across north Queensland. Several hundred hectares of gamba grass have been grown near Mareeba to produce commercial seed and it is currently spreading along roadsides and to adjacent open woodland. It produces up to 10 times more biomass than native grasses, and provides abundant fuel for fires of greater intensity than fires associated with native grasses (Rossiter et al. 2003). Tree mortality has been shown to be greater in fires associated with gamba grass indicating this grass has the capacity to change the native vegetation structure (Rossiter et al. 2003) and the burning regimes in some areas of the WTR where burning is either a regular event or used in management regimes. Based on its proven weed potential and environmental impacts elsewhere, Csurhes (2005) recommends that in Queensland, gamba grass be removed from sale, planting be stopped, isolated infestations be eradicated and other infestations be contained.

Actions and Outcomes

National

As the number of invasive plants in Australia increases, so does the number of management approaches to address them. To date many approaches appear to be reactive rather then strategic. The need to be more strategic is now changing how weeds are addressed. The National Post-border Weed Management protocol was developed to ensure standardisation in decision support systems for prioritisation of weed management strategies at state or territory and national levels (Virtue and Panetta 2006). It includes the key criteria that should be considered in assessment such as weed risks posed by different plant species and the feasibility of managing these species through coordinated control programs. The protocol can be used for determining: which species should be on noxious weed lists, priorities for eradication or containment programs, priorities for management action against new weed incursions, plant species with existing or potential commercial uses which pose a weed risk and require active management to keep them contained and priorities for investment in research and extension work.

When a weed species is declared a WoNS, the responsibility for its containment or eradication becomes a national one and national action strategies have been developed for each species, however landowners are still required by law to control a declared WoNS when it occurs on their property. Of the twenty species declared as WoNS, five are found in the WTR. They are: *Annona glabra*, *Hymenachne amplexicaulis, Cabomba caroliniana, Salvinia molesta* and *Alternanthera philoxeroides*. The national action strategies for these weeds have four main components (Table 7) and may differ slightly to address issues specific to each species. The four main components of the action strategies are:

- Early detection;
- Prevention of spread;
- Research; and
- Education and awareness.

Table 7. Main components of National Action Strategies for the WoNS occurring in the WTR (DEH 2006).

Species	Early Detection	Prevention of Spread	Research	Education and Awareness
Annona glabra	• Develop procedures for early detection	• Eradicate isolated infestations • Contain well established infestations • Develop long term control programs	• Identify potential areas at risk of infestation from water currents • Identify biocontrol agents	• Targetted education programs and awareness campaigns to increase community awareness of weed impacts and control methods
Hymenachne amplexicaulis	• Undertake delimiting surveys	• As for *A. glabra* • Local control where negative impacts are unacceptable to local community	• Ecology and management • Registration of herbicides • Application to be a biocontrol target	• As for *A. glabra*
Salvinia molesta	• Undertake early detection programs	• Ensure availability of biocontrol agents to all infested regions • Best practice workshops • Eradicate or contain infestations at high risk of spread • Emergency response plan for *S. molesta* hotspots	• Integrated management in temperate climates	• Target boating, fishing, local government, aquatic plant trade industry for awareness campaigns • Aquatic WoNS identification training
Cabomba caroliniana	• As for *S. molesta* • Assess (current and potential) economic and ecological impacts • Develop best practice manual and workshops	• As for *S. molesta*, including wash down facilities and signage	• Field trial of herbicide delivery mechanisms • Assess suitability of biocontrol agents	• As for *S. molesta*
Alternanthera philoxeroides	• As for *C. caroliniana* • Assess non-herbicide/biocontrol options	• Eradication/containment of priority infestations • Identify and map areas at high risk of spread	• Identify biocontrol agents • Techniques for integrating biocontrol with herbicide control • Study biology and ecology of *A. philoxeroides* • Develop mycoherbicides	• As for *S. molesta,* include earthmoving contractors and landholders in target audience • Awareness programs with ethnic communities

The National Environmental Weeds Alert List was compiled in 2000 by the DEH, listing ‘sleeper species’ which are plant species that are in the early stages of establishment that have the potential to have a significant impact on biodiversity if they are not managed. It comprises 28 non-native plant species that have become naturalised in the wild (Table 8). Twelve of these 28 non-native species are distributed or have the potential to be distributed in Queensland. One of the two species that occur in the WTR, *Chromolaena odorata*, is the subject of a nationally funded eradication program.

Table 8. The National Environmental Weeds Alert List (C of A 2006e), showing only those species that are or have the potential to be distributed in Queensland. (*) = present in the WTR.

Common Name	Scientific Name	Extent in Australia	Potential Distribution
Barleria or porcupine flower	*Barleria prionitis*	QLD, NT	WA
Chinese rain tree	*Koelreuteria elegans* ssp. *formosana*	QLD	NSW, NT, WA
Chinese violet	*Asystasia gangetica* ssp. *micrantha*	NSW	QLD, NT, WA
Cutch tree	*Acacia catechu*	NT	QLD, WA
Cyperus	*Cyperus teneristolon*	NSW	QLD, VIC, SA, WA
Karroo thorn	*Acacia karroo*	QLD, NSW, SA, WA	
Laurel clock vine	*Thunbergia laurifolia* *	QLD	NT, WA
Leaf cactus	*Pereskia aculeata*	QLD, NSW	WA
Praxelis	*Praxelis clematidea* *	QLD	NT, WA
Rosewood or tipuana tree	*Tipuana tipu*	QLD	NT, WA
Senegal tea plant	*Gymnocoronis spilanthoides*	QLD, NSW	
Siam weed	*Chromolaena odorata* *	QLD	NT, WA

In 2006 a National Weed Spread Prevention Action Plan was prepared by the National Weed Spread Prevention Committee (DNRMW 2006). Its aim is to 'reduce the risk of weed spread caused by human activity within Australia', since this is the most common way weeds species are dispersed over both local and long distances. Invasive garden plants account for 70% of the combined agricultural, noxious and natural ecosystem weeds in Australia. They affect a wide range of vegetation types over vast areas, e.g. the rubber vine *Cryptostegia grandiflora* introduced as an ornamental plant now covers an area of over 20% of Queensland (Groves et al. 2005). The potential for invasive garden plants to spread to new places is aided by the lack of uniformity in legislation at state and national levels. This means that 40% of invasive garden plants that have been declared as noxious weeds may still be available for sale in other parts of the country (Groves et al. 2005, Table 9).

For example, of 57 garden plant species that have been declared as noxious weeds in Queensland, 35% are available for sale in other jurisdictions (Groves et al. 2005). In an effort to address this problem, an initiative by the Australian Weeds Management CRC and the Nursery Industry Association of Australia requested commercial garden nurseries to voluntarily remove such plants from sale. This initiative was unsuccessful, most likely because it was voluntary rather than compulsory. Groves et al. (2005) also recommended as a priority, a national ban on sales of species that are declared WoNS, species that are on the Alert List, those that are declared or noxious and those that impact on rare or threatened plants. This was supported by Glanznig (2006) who states that laws (rather than voluntary action) are needed to ensure all growers and sellers comply and that a national noxious weed list be compiled that includes high-risk plant species that are yet to naturalise or are not yet widespread. Glanznig (2006) outlines nine other points for mitigating the risk posed by invasive garden plants, as part of a policy package aimed at dealing with invasive garden plant issues. These include recommendations for improved risk assessments of plant species, a greater focus on low risk garden plants, a greater understanding of the weed status of garden plant species by the garden industry, encouragement of the garden industry to support minimising the impact of invasive garden plants and community involvement in the detection of new invasive plant specie

Table 9. The ten most serious invasive garden plants still available for sale by nurseries in Queensland (from Groves et al. 2005).

Scientific Name	Common Name
Coreopsis lanceolata	Coreopsis
Gloriosa superba	Glory lily
Psidium guajava and *P. guineense*	Guava
Lonicera japonica	Japanese honeysuckle
Ochna serrulata	Mickey Mouse plant
Murraya paniculata cv. *exotica*	Mock orange
Myriophyllum aquaticum	Parrot's feather
Catharanthus roseus	Pink periwinkle
Colocasia esculenta	Taro
Allamanda cathartica	Yellow allamanda

State and Regional

The Strategic Weed Eradication and Education Program (SWEEP), an initiative of DNRMW, recognises that environmental weed problems need to be managed at their source before dealing with the symptoms further downstream, and provides a means of early detection and response to new weeds by using volunteer groups for implementing activities to reduce, control and manage the spread of environmental weeds. However, while management of economic weeds is supported by legislation and government programs, volunteer groups that attempt to control and manage environmental weeds are under-resourced.

The NAQS a sub-set of AQIS, provides early warning and prevention (if possible) of new weed threats entering northern Australia. They undertake surveys within 20 km of the coast of northern Australia from Broome to Cairns and in the Torres Strait Islands, East Timor, Indonesia and PNG. Survey frequency is determined by perceived threats to the individual risk areas within the NAQS zone, e.g. inhabited Torres Strait islands are considered high risk due to their proximity to PNG, whilst the southern coast line of Gulf of Carpentaria is considered to be the lowest risk (Waterhouse 2003). NAQS has its own target lists of candidate weeds (Table 10) upon which to focus survey efforts (Waterhouse and Mitchell 1998, cited in Waterhouse 2003), although any new weed detected during surveys is noted, regardless of whether it is on the target list. The target list species are known to occur in areas adjacent to Australia and are not yet fully established in Australia.

Up-to-date inventories of the weed flora, validated by voucher specimens in major herbaria, are essential for prioritising weed management activities in any region. The surveys in PNG are unlikely to identify every new weed that has arrived, but will increase awareness of some of the major and emerging weed problems in the region. NAQS activities resulted in the early detections of *C. odorata, M. micrantha, L. flava, C. hirta and M. racemosa* in Australia (Waterhouse 2003). All of these species are currently subject to the eradication programs: The Siam Weed project (Maher and Funkhouser 2006) and the 4TWP, respectively.

The 4TWP is a collaborative program between DNRMW, EPA, nine local governments, community-based organisations (e.g. Conservation Volunteers Australia), CSIRO (modelling and research) and international institutions working on the management of these weed species. It has led to the development of science-based performance criteria, including biological indicators of control, standardised terminology for recording data, the development of a Tropical Weeds Database allowing review of data relating to plant population changes that are linked to a mapping platform, the development of property pest management plans and industry codes of practice. It has focused surveillance for clidemia and miconia through the annual 'Melastome Taskforce for Single Infestations', by holding it at the same time as National Weedbuster Week, and awareness raising activities through the media has led to the early detection of isolated occurrences of the weeds at a stage where eradication is feasible and highly cost effective.

Table 10. The NAQS target list of candidate weeds (from Waterhouse 2003).

Scientific Name	Common Name
Amaranthus dubius	Chinese spinach
Austroeupatorium inulaefolium	
Chromolaena odorata	Siam weed
Mikania cordata	
Mikania micrantha	mile-a-minute
Cleome rutidosperma	spiderflower
Fimbristylis umbellaris	globular Fimbristylis
Schoenoplectus juncoides	
Scirpus maritimus	
Equisetum ramosissimum	horsetail, scouring rush
Eriocaulon truncatum	
Croton hirtus	
Mucuna pruriens	velvet bean, cow-itch
Myriophyllum spicatum	Eurasian watermilfoil
Hyptis brevipes	lesser roundweed
Limnocharis flava	yellow bur-head
Rotala indica	toothcup
Clidemia hirta	clidemia, Koster's curse
Rhodomyrtus tomentosa	downy rose myrtle
Boerhavia erecta	
Piper aduncum	
Brachiaria paspaloides	common Brachiaria
Coix aquatica	Job's tears

Control at species level, however, has brought its own set of issues. For example, the control of clidemia is complex due to the density of some infestations. Its removal could result in severe soil erosion or the sudden germination of other weed species that could then prevent the re-establishment of native species (Smith 1993, cited in Breaden, unpubl.). Mechanical removal of plants (hand pulling) has been undertaken approximately every six weeks to reduce the risk of re-infestation (P. Lawler, pers. comm. 2004, cited in Breaden 2007, unpubl.), although in some environments this is not as effective due to the plant's ability to take root readily when damaged (DeWalt et al. 2004, Smith 1993, Tunison 1991, all cited in Breaden, unpubl.). A combination of hand pulling and application of herbicides every three to six months has been used to control the miconia and mikania, and hand pulling of limnocharis every three weeks has been undertaken.

Data about miconia infestations are being compiled from the various shires involved in the 4TWP to create a database that includes site location and survey information details (S. Devaney, pers. comm.). At many of the treated sites in north Queensland, subsequent regeneration from seed has been low, usually a small percentage of the pre-treatment population.

C. odorata was targeted for eradication in 1994 and a SWEEP team was employed to eradicate the infestation. Surveys by foot, in motor vehicles, boats and helicopters were undertaken from May to July during the plant's peak flowering period, a time that allowed easy identification of the plant. New infestations were still being found in the Tully area eight years after the eradication program began, however the amount of chemical used by the program and the number of new infestations have declined each year. Staff are still employed for on-ground detection and control. The main hurdles to the eradication of *C. odorata* have been knowing where the plant is, ownership of the weed problem (though this attitude is changing) and reluctance of some members of the community to come forward with information on its distribution (Setter and Vitelli 2003). The QPWS has been involved in eradication programs for *C. odorata* as well as eradication programs for miconia, hymenachne, thunbergia and pond apple infestations throughout the WTR. In 2004, a $213,000 NHT-funded WoNS project, the Pond Apple Control Project, which had involved QPWS, WTMA, local government and community groups, was successfully completed. Its aim had also been to map known and potential areas of infestations, conduct trials to determine the most effective way to control pond apple in a range of situations and raise public awareness of the pond apple issue (WTMA 2005).

Weed control information sheets and a WTR guide to weed identification have been produced and are available on WTMA and DNRMW websites (WTMA 2003). Revision of WTMA's grazing policy in 2003-2004 has resulted in the phasing out of cattle grazing in the WTWHA except where it has been shown to be beneficial to WH management. This is due to the capacity of cattle to trample, graze and introduce and spread exotic pasture species and other weeds to the area (WTMA 2004).

Local

At the local level, local governments within the WTR have all developed LG PMPs for on-going weed control and Codes of Practice have been developed for weed management associated with road construction works and electricity supply, which are the two main areas associated with weed introduction and spread. Although there are weeds of concern common to all shires, e.g. hymenachne, the focus of weed control programs varies from shire to shire. For example, in the Johnstone and Douglas Shires, pond apple is the main concern, in the Eacham shire, tobacco weed is the main focus and Cairns City Council is focused on sicklepod, giant sensitive plant and panama rubber.

As part of the WTMA Good Neighbours program, weed spray units have been provided to four WTR shires by WTMA for use by WH landowners and neighbours. This enables landowners to control major outbreaks of weeds such as hymenachne, giant sensitive weed, sicklepod and siam weed. The program, in conjunction with local councils, has also funded lantana biocontrol expert visits and releases of biocontrol agents in the WTR (WTMA 2003).

Aquatic Weeds

Species of Concern

Most of the aquatic weeds in Australia appear to have been deliberate introductions, either as pasture grasses for the cattle industry or as ornamental pond plants, or, as a result of dumping or release from aquaria (AIMS 1995, BRS 2007). They have had devastating effects on waterways across northern Australia. Due to the similarities in life forms and the environments in which they occur, the environmental impacts of these aquatic and semi-aquatic plants are all similar. As well as the impacts listed in Table 11, these weeds also cause the loss of food sources such as fish and waterbirds, that are important to indigenous people. The weeds affect high conservation areas and tourism industries that depend on the appeal of wilderness areas (e.g. Kakadu) and the dense weed mats prevent aquatic activities such as boating, swimming and fishing.

Werren (2001) identified seven aquatic species as priority weeds; five of which were also identified by Bebawi et al. (2001) as requiring research and three of which are WoNS (Table 11). Aquatic weeds are covered under the same policy frameworks outlined for Terrestrial weeds.

Table 11. Aquatic weeds of concern and the environmental impacts they commonly cause in the WTR, identified by the Weed Risk Assessment developed by Werren (2001). The impacts of E. canadensis, S. graminea ssp. platyphylla, and A. philoxeroides are not significant in the WTR at present. (*) = WoNS.

Scientific name	Common name	Environmental impacts commonly caused by these plant species
Eichhornia crassipes	Water hyacinth	• Chokes waterways. • Increases water loss via transpiration. • Shades out native aquatic plants. • Causes habitat loss. • Provides breeding ground for mosquitoes. • Reduces dissolved oxygen and water quality, resulting in stagnant water. • Causes death of aquatic biota. • Reduces animal access to drinking water. • Thrives in nutrient-rich water. • Increases extent of flooding.
Pistia stratiotes	Water lettuce	
Salvinia molesta *	Salvinia	
Elodea canadensis	Canadian pondweed	
Sagittaria graminea ssp. *platyphylla*	Arrowhead	
Cabomba caroliniana *	Cabomba	
Alternanthera philoxeroides *	Alligator weed	

Water Hyacinth (*Eichornia crassipes*)

Water hyacinth, *Eichornia crassipes*, is native to South America and was introduced to north Queensland as an ornamental in fish ponds and aquariums. It reproduces vegetatively and also produces vast quantities of seed. Water hyacinth grows rapidly and forms dense floating mats of vegetation that choke out native vegetation and block waterways. Due to active transpiration of water through the leaves, water hyacinth acts like a floating water pump and contributes greatly to evaporation of water from wetlands.

Water Lettuce (*Pistia stratiotes*)

The water lettuce, *Pistia stratiotes,* is a free floating aquatic weed that rapidly forms dense mats covering rivers, dams and irrigation channels. It is spread by seed and vegetative reproduction. Water lettuce was introduced as an aquarium and water garden specimen, but as a result of flooding or dumping, the plant is now found throughout eastern Queensland. It is listed amongst the three worst aquatic weeds in the world (Calvert 1998) and in Queensland is a declared Class 2 plant which means that landholders are responsible for its control if it is present on their property. A local government may serve a notice on a landholder requiring them to control declared pests (DNRW 2006).

Salvinia (*Salvinia molesta*)

Salvinia is a free-floating fern that forms dense floating mats of vegetation. It reproduces vegetatively and grows extremely rapidly, doubling in size in just three days. It grows best in nutrient-rich waters, such as wastewater or where there is agricultural run-off and can also survive long dry periods. Salvinia is a serious weed throughout Africa, India, Sri Lanka, south-east Asia, the Phillipines, PNG, NZ, Fiji, Hawaii and mainland USA.

Hymenachne (*Hymenachne amplexicaulis*)

Hymenachne *Hymenachne amplexicaulis* is a fast-growing perennial semi-aquatic grass. It is a prolific seeder and will set roots on broken stem fragments. Seed is transported downstream by floodwaters and also can be spread in mud attached to animals, such as cattle. Hymenachne forms dense monospecific stands of vegetation that exclude native vegetation. It was approved for release in Queensland in 1988 and was planted in the tropical wetlands of north Queensland and the NT as ponded pasture for the cattle industry. Hymenachne now invades permanent water bodies, seasonal wetlands, sugar cane growing country and drainage ditches throughout the WTR (Csurhes et al. 1999, CRC Weed Management and DEH 2003). It is currently estimated to cover between 2000-3000 ha in the WTR (A. Doak, pers comm.), with half of that being in the Hinchinbrook Shire.

Para Grass (*Brachiaria mutica*)

Para grass, *Brachiaria mutica*, is a perennial grass that was also originally introduced as ponded pasture for the cattle industry (DNRW 2006). It grows in low-lying wet ungrazed areas as well as in deep soils in non-swampy areas, is common in sugar cane growing areas, and can penetrate disturbed native vegetation in areas with wet soils. When not grazed, it forms dense blankets that float on water, excluding native vegetation, it also modifies wetland faunal communities and can reduce water flows (Douglas et al. 2001). Because it is found across a broad range of water depths it can invade most wetland and riparian areas and can significantly alter fire regimes in these habitats. Para grass occurs widely throughout the WTR.

Cabomba (*Cabomba caroliniana*)

Cabomba is a popular aquarium plant that rapidly grows to form a dense monoculture. It regenerates through fragments taking root and can quickly achieve extremely high biomasses. The large amount of plant material produced can choke waterways, exclude native vegetation, reduce storage capacity and taint water supplies. The WTR creeks that have cabomba infestations have lower abundances of platypus and water rates (DNRW 2006b). It occurs in several places in the WTR, particularly in Leslie Creek on Atherton Tablelands and has the potential to spread throughout eastern and northern Australia's waterways.

Alligator Weed (*Alternanthera philoxeroides*)

Alligator weed, *Alternanthera philoxeroides,* grows in water and on land and is believed to have been brought to Australia in ballast water in the 1940s from the neotropics. It is a serious invasive weed in the US, China, India, South-East Asia and New Zealand. In Australia, most infestations are in NSW, with infestations in Cairns, Brisbane and Canberra (CRC Weed Management and DEH 2003). Some infestations were the result of the plant being cultivated as a herb by some Sri Lankan communities, it had actually been mistaken for another herb that is closely related. The infestation that was reported in Cairns was one such instance and it has since been eradicated. Although no further infestations have been reported in the WTR, alligator weed has the potential to become widespread throughout the tropics and sub-tropics. Small stem fragments can set roots if they contain at least one node, and it is often spread downstream when the plant is broken up by floods, or following mechanical or chemical control. It has been spread between catchments as a contaminant in garden mulch and landfill, attached to machinery, vehicles and animals. Alligator weed rapidly achieves extremely high biomass, can cover the entire water surface and impede waterflow. Because of its high biomass, alligator weed can reduce oxygen exchange, with negative impacts for the instream community and water quality (Weed CRC 2003).

Actions and Outcomes

National and State

The control programs for hymenachne, cabomba, salvinia and alligator weed are overseen by national management committees since they are declared WoNS. The action strategies for these species are as described in the Terrestrial weeds National Actions and Outcomes section. A summary of the strategies is given in Table 7.

Several biocontrol agents for the control of water hyacinth *E. crassipes* were released in Australia in the 1970s and 1980s, and are said to have achieved good control in sub-tropical and tropical eastern Australia. Two more agents, a weevil, *Neochetina eichhorniae,* and a moth, *Niphograpta albiguttalis*, were released in the 1970s and another weevil, *Neochetina bruchi*, was introduced in 1990. A moth, *Xubida (Acigona) infusella*, was released in Australia in 1981 but only limited establishment has occurred in southern Queensland. However, the two weevils have successfully cleared large infestations of water hyacinth overseas (CSIRO Entomology 2007a). Physical removal of the plant has been successful, but in localised areas.

Surveillance and physical removal of new infestations whilst numbers are low, as well as public education to prevent further dumping of the plants in waterways, are the main management actions for water lettuce. Two weevils (*Neohydromonus pulchellus* and *Orchetina bruchi*) have been introduced as biocontrol agents, with some success on dams between Bundaberg and Brisbane. Herbicides have been recommended for large infestations, however integrated control which includes a combination of mechanical, biological and chemical methods that complement each other is said to be the most effective strategy for large infestations (DNRW 2006).

Most regions restrict the importation and sale of salvinia, however inconsistency about requirements for control of salvinia across jurisdictions still occur. The weevil, *Cyrtobagous salviniae,* has been a successful biocontrol agent in controlling salvinia in sub-tropical and tropical areas since its first release at Lake Moondarra, near Mt Isa, in 1980. It has reduced extensive infestations to a few small patches in Qld, NT, PNG and Sri Lanka (Room et al. 1981, CSIRO Entomology 2007a). In areas where biocontrol has not been introduced, physical removal of the plant has been successful in localised areas only because of the plant's ability to spread rapidly from a single plant (CRC Weed Management and DEH 2003).

Prevention of further spread of salvinia is thus the focus of management action. As it is mostly spread by human activities, such as on boating equipment, hygiene protocols and greater public awareness about the problems salvinia can cause is required, as well as cooperation from the aquarium and nursery industries to enforce the laws banning the sale and trade of salvinia, and to encourage the use of alternative native species (CRC Weed Management and DEH 2003).

There is currently no legislation dealing specifically with ponded pasture development or management in Queensland. However in 2001, the Queensland Government released its 'Policy for development and use of ponded pastures', recommending against the use of hymenachne, para grass and aleman grass in ponded pastures in recognition of their invasiveness potential (DNRMW 2006). Management of hymenachne has centred on preventing its spread into uninfested catchments, however this is difficult because the main vectors of spread are floodwaters and waterbirds. Control involves regular monitoring of 'at risk' catchments and regular application of herbicides, as mechanical or physical removal is ineffective due to the plant's ability to set roots from very small pieces. In 2003, hymenachne was declared a Class 2 noxious weed in Queensland (CRC Weed Management and DEH 2003).

Continued monitoring, containment and quarantine are the main actions taken to control alligator weed. Physical removal of plants and revegetation, or repeated herbicide treatment during the growing season have been more effective for land infestations than biocontrol. However, removal of plants can sometimes result in an increase of the spread of the weed if fragments are left behind. Awareness-raising of the problems caused by alligator weed has also been helpful for the detection of new infestations.

Regional and Local

Hymenachne has invaded all the major water bodies within the Hinchinbrook Shire. Its impacts include loss of fish habitat, reduction in tourism potential of conservation areas and blockage of drainage channels. The Hinchinbrook Shire Council (HSC) has mapped the distribution of the weed throughout the region's wetlands and waterways and identified areas for priority control, e.g. infestations in upper catchments. With NHT funding, an eradication program was begun which involved trialling the use of herbicides and controlled burns. It found that repeated herbicide applications over the long term would be required to prevent re-infestation as well as monitoring and adequate funding to maintain this treatment. Other control techniques such as solarisation which involves covering the plants with dark plastic has been successful at a localised scale. Shading by tall vegetation to reduce the amount of plant material infesting rivers and creeks is considered more ecofriendly than chemical methods but its effectiveness is limited on seasonally inundated floodplains. The use of alternative pasture species such as the native hymenachne H. acutigluma has also been recommended, however, because it is difficult to propagate, it has not been widely used. Biocontrol is also limited as it would require a target-specific agent that would not attack this closely related native hymenachne (CRC Weed Management and DEH 2003).

The combined use of herbicide and fire was trialled as a way of controlling a small infestation of Para grass near Weipa, on Cape York Peninsula (Gould 2001), but eradication was not achieved due to unexpected rainfall which meant that treatment, which relied on dry weather, was not as effective as anticipated and treated plants regenerated. Further studies have not been undertaken due to lack of resources. A trial by Williams et al. (2005) found that short-term cattle grazing was effective in reducing Para grass on the Townsville Town Common and this is under further investigation.

There are currently no effective methods available to control *C. caroliniana.* The search for a suitable biocontrol agent for cabomba which exists in a wide climatic range from tropical to cold climates continues. Trials are underway in south east Qld of a stem boring weevil (*Hydrotimetes natans*) and an aquatic moth (*Paracles* spp.) (Schooler et al. 2006). Surveys of cabomba populations are being undertaken at three lakes in south-east Queensland, as well as observations of cabomba in its native range, and investigation of how the realized niche of cabomba might be affected by herbivore damage.

Hymenachne, water hyacinth, salvinia and cabomba are classed as Category 2 weeds by the FNQROC which means they are of medium priority and are to be contained and reduced in extent, where possible (FNQLGPPAC RPMP 2006).

Synthesis of Management Actions for Invasive Plant Control

The listed aquatic weeds (Table 11) are either WoNS or State-declared weed species, reflecting the seriousness of their current and potential environmental impacts. The similarities in the weed life forms, the environments where they occur and the ways they reproduce and disperse have meant that their impacts are also similar. This may mean that there is scope for common management approaches that take advantage of commonalities rather than investing entirely in programs that hinge on the individual characteristics of each species, e.g. changing nutrient-levels of drainage channels. In general, however, these weeds have been present in the WTR for long enough to become established and are generally considered to be too widespread for complete eradication to now occur, thus management is focused on prevention of further spread into uninfested areas, ongoing surveillance and raising public awareness of the problems these weeds cause.

The fact that all the weeds listed in Table 11 appear to have been deliberate introductions to the WTR indicates how important it is to address social and cultural attitudes toward the plants, not just within the community but also in government and land management agencies, such as the DPIF and CSIRO's Plant Introduction program. An impact assessment of 66 priority invasive weeds in south-east Queensland by Batianoff and Butler (2003), states that humans deliberately introduced 93% of these priority weeds and that humans, animals and water are the main vectors of the weeds.

In a review of deliberate plant introductions as part of government plant introduction programs during the past 70 years, Cook and Dias (2006) conclude that weeds researchers have underestimated the magnitude of propagule pressure (i.e. the chance of successful establishment of a species increases as the number of introduction events, number of introductions sites and number of introduced individuals released also increase), as well as the genetic range of species enabling them to tolerate a wide range of environmental conditions. They suggest that although efforts to limit the potential introduction of weeds into Australia is important and could be assisted by more thorough risk assessments, focus should be centred on potential sleeper weed species that are already here, that are left over from and located at old plant-introduction experimental sites across Australia. Although not investigating these old plant-introduction experimental sites, the Queensland Herbarium is currently collecting weeds and searching for potential sleeper species to gain a representative and relatively accurate description of the distribution of naturalised flora in Queensland. This includes surveys that radiate out from early, abandoned and more established settlements, e.g. old mining towns and along old railway tracks and roads, as these usually have more introduced plant species than currently expanding or new settlements. The surveys are currently funded by and are a part of a CRC Weeds project, however the work will be on-going to provide an up-to-date weed distribution of naturalised plants in Queensland (G. Batianoff, pers. comm.).

Many of the introduced pasture grasses that have become weeds were specifically selected for their weedy characteristics, such as their ability to tolerate extreme environmental conditions, spread rapidly, withstand grazing and compete with native plants (Calvert 1998).

Reluctance to declare them as noxious weeds because they are still perceived to be of value to the agricultural sector, ongoing inadequate risk assessments of deliberately introduced plants, and the lack of understanding of the history of plant introductions are all major obstacles to preventing further introductions of environmental weeds. Weiss et al. (2006) state that the most likely pathways for deliberate introductions of weed species in Victoria include the seed, nursery and garden, landscaping and aquarium/pet shop industries and the plants would be distributed via the community or by business. Carr 1993, cited in Weiss et al. (2006), estimated that as much as 65-70 % of the 1221 naturalised introduced taxa in Victoria had been deliberately introduced. Similarly in the United States, it has been estimated that 85% of the invasive woody plant species were deliberately introduced for horticultural purposes (Reichard and Hamilton 1997).

One of the most obvious ways to manage and reduce this risk of deliberate introduction is through legislation and declaration of the plant as a noxious weed. Importantly, declaration also requires extension and enforcement to ensure compliance with legislation. Inconsistencies in legislation across states and territories mean that invasive plants can be moved around the country to states where the plants do not have the same status. To overcome this problem, Groves et al. (2005) propose that federal legislation is required and only then will there be a chance to control invasive species. However, in a study in the USA, Maki and Galatowitsch (2004) found that legislation alone is not adequate for restricting the movement of prohibited plants.

The most common available methods of control for aquatic weeds in the WTR include physical or mechanical removal of plants, application of herbicides, biocontrol, or combinations of these. Removal of plants is effective at a localised scale for some weed species whilst the numbers of plants are still low, but it is not effective on those species that take root from stem fragments, and regular surveillance and monitoring to detect new incursions are required. Perna and Burrows (2005) state that the mechanical removal of water hyacinth from lagoons is justified because it can result in rapid and substantial increases in dissolved oxygen saturation, and improved habitat suitability for fish, however, they recommend that upstream infestations be addressed first due to the presence of the weed in drainage channels.

The application of herbicides is often recommended to control aquatic weeds; their application in close proximity to water means that ensuring the chemicals used are safe and do not have adverse effects on other parts of the ecosystem is of great importance. The problem of weed resistance to herbicide and using herbicides that are target-specific are major considerations and long term commitment of resources to maintain follow-up treatments, e.g. against hymenachne, is also required and not always possible.

Biocontrol has been effective on several weed species, e.g. aquatic alligator weed and salvinia, and is reported to be most effective when used with a combination of other methods, including fire. But finding a suitable biocontrol agent and testing it for suitability takes a long time and has a low success rate, e.g. at least four biocontrol agents have been released for the control of water hyacinth but despite success overseas all have had limited success in Australia (CSIRO Entomology 2007).

Habitat manipulation and restoration has been trialled and shows some potential as long term, more environmentally benign methods of control, e.g. shading out Para grass with native riparian vegetation (Bunn et al. 1998); however, its effects on other parts of the ecosystem must also be considered. It is interesting to note that the aquatic weeds listed are reported as thriving in nutrient-rich water; this suggests that addressing issues such as correct fertiliser application and reducing run-off from agricultural and horticultural lands is also important. Such issues are already being addressed in actions taking to reduce the runoff into the Great Barrier Reef lagoon (O'Reagain et al. 2006, Coetzee et al. 2007).

Potential Future Threats and Capacity to Meet Them

A continuing threat to the WTR is new incursions from outside the region and the country. While movement of species into both the WTR and into Australia is to some extent a natural process, the contribution of human introductions is overwhelming with many incursions occurring as a result of national and international trade. A key weakness is our ability to detect plant imports as part of this open trade, let alone as smuggled goods. Seeds are easily transported and even if inspected, false or unintentional incorrectly-labelled seed can decrease the chance of detection. In addition, movement of plants that are included in household effects from elsewhere in Australia or seeds that are contaminants of other objects means that all movement, not just trade, into the region needs to be considered in planning incursion prevention. While new regulation and self-regulation of the nursery industry will go partway to meeting some of these threats, the broad nature of the potential introduction pathways and vectors means that complete prevention cannot be expected. At the very least, Australia has one of the world's best risk assessment procedures and this needs to be applied rigorously in monitoring imports into the country.

In stakeholder consultation, inadequate risk assessments for plants that are to be intentionally introduced was also identified as a major threat, with the potential to result in a host of environmental weeds arriving in the WTR. To some extent there have been moves within the nursery industry to become more ecologically responsible by no longer selling plants that are known to be potential weeds, although these restrictions are not yet compulsory. One problem in this context is how to monitor the trade of plants between private plant collectors through mail order, markets, and the internet. Morley (2007) recently reported that several plants species that are declared Class 2 noxious weeds in Queensland were being offered for sale on the internet auction site eBay. In response, Biosecurity Queensland stated that there is an on-the-spot-fine of $1500 for anyone found buying or selling a declared plant within the state, but the difficulty is actually catching guilty people.

Having entered the region, invasives need to become established and begin the spread phase before they are identified as invasives. The WTR is already home to many sleeper weed species, many of these being grown as garden plants. Past experience indicates that many of these species will remain innocuous however a small percentage will go on to become invasives. As a rough guide, Smith et al. (1999) cite the 'tens rule' introduced by Williamson and Fitter (1996). This rule estimates that only 0.1% of species that are originally introduced into a new environment are expected to become pests. This has been found to be true for a variety of British animal and plant species and pasture plants in the NT (Lonsdale 1994), however it is a crude measure of invasibility and may not always be correct.

Critically, our capacity to meet this threat is limited in that we have few tools that assist identification of potentially and imminently invasive species and that can distinguish those that are likely to become high impact invasives. The research priority list of Bebawi et al. (2001) and the risk priority list of Werren (2001) have raised the awareness of present and future weeds of high risk to the WTR so that research projects and management strategies can be prepared ahead of time. These approaches need to be further refined to include expected interactions within native communities.

Finally, climate change has the potential to shift the thresholds for invasion and spread for a wide variety of invasive plants (Goosem 2003). Such changes would occur in part through changes in the availability or access to particular environmental envelopes within regions favouring particular invasives. Climate change may also facilitate weed spread by acting as a long-term disturbance process, driving changes in species composition, and in the strength and periodicity of major natural disturbances, e.g. dry periods and cyclones. These effects may facilitate invasions by altering community structure and providing new opportunities for establishment after disturbance. Some of our current invasives are able to capitalise on disturbance, e.g. *Miconia calvescens* (Meyer 1997, H. Murphy, pers. comm.) and might be predicted to become significant concerns under these conditions.

Synthesis of Research Contributions to Management of Invasive Plants

Weed control in the WTR has historically focused on major infestations of long established weeds, with not surprisingly, little success. The initiative to take a more strategic approach toward weed control in the WTR and focus management efforts and resources on 'newly arrived' environmental weeds where eradication is considered feasible, has been a major change in tactics. The establishment of the 4TWP that targets four newly arrived weeds in the WTR has resulted in a coordinated and effective weed control strategy, the basis of which could be applied to other potential environmental weeds in the WTR. However, addressing weeds on a species by species basis is still not as cost effective as it could be.

Over the years much has been made of the use of remote sensing to detect weed infestations, since it has the potential to allow remote surveillance of large and inaccessible areas within the WTR. However, the methodology requires further work and improvement in resolution and the processing of images to address the huge variation in reflectance in rainforest vegetation, so that individual weed species can be identified (Ticehurst et al. 2003, Harriss and Gillieson 2006). Resources that have been allocated to investigation of the use of remote sensing have not been insignificant, but there have been few practical returns due to the limitations of technology in producing images suitable for use. Therefore it may be beneficial now to undertake a review of investment in this aspect of weed surveillance in the WTR.

There has been a recent increase in research that focuses on similar weed species characteristics, e.g. plant functional groups, which refer to groups of plants that share environmental responses. Functional group approaches assume that while particular species may be distinct in terms of their ability to extract resources, differences between species are often sufficiently small that groups of species can be considered to be functionally similar. This is likely to be particularly true in high diversity ecosystems, such as the rainforest ecosystems of the WTR. The use of functional group approaches is common in ecological studies as it allows one to cut through the complexity and redundancy of individual species interactions and to reduce the interactions to those between groups that are perceived to be significantly different. This approach has been applied in the WTR to a description of dispersers and seeds (Dennis and Westcott 2006), estimation of weed dispersal distances and appropriate search zones for eradication efforts (Westcott and Dennis 2003, 2006) and consideration of the relative regeneration niches of invasive and native species (Murphy et al. 2007, in prep.). Elsewhere in Australia functional group approaches have been applied to the identification of plant functional groups and associated bird-dispersal syndromes to understand how environmental weeds are spread by birds (Stansbury 2003, Moran 2003).

Fruit characteristics could be used to predict disperser functional groups and potential dispersal distance from infestation foci (Westcott 2003). This information would aid delimitation of minimum search area, and the processes that drive some species to become invasive, e.g. understanding of the role of riparian and creek corridors in dispersing high impact weedy vines through the landscape (Vivian-Smith 2003), with the aim of addressing environmental impacts at community and ecosystem level rather than at species level. Many studies have been undertaken to try and identify sets of characteristics that distinguish plants that are going to be weeds. Although there are no definite sets, there are some generalities that enable many plants to be successful weeds.

Following Hobbs and Huenecke (1992) there has been an assumption that disturbance facilitates invasions. Examination of this assumption shows that the situation can be complex. This assumption implies that invasive species outperform native species, particularly in the face of disturbance. A meta-analysis of studies of the relative performance of invasives relative to natives found no statistical difference between the two and that natives outperformed invasives when a variety of growing conditions were considered (Daehler 2003). In addition, not all invasives are equal and high performance by an invasive under a particular disturbance requires the appropriate species with an appropriate set of traits (Horvitz et al. 1998). While the performance of invasives may be no better than that of natives under some conditions, human induced disturbances tend to be highly unusual in nature and thus may favour invasive functional types.

The work of Murphy et al. (2007, in prep.) suggests that in the WTR invasive species are weak invaders under most "standard" or undisturbed rainforest conditions where the functional diversity of native species is highest, i.e. they can enter the community but do not dominate it. In contrast, native functional diversity is at its lowest under disturbance regimes that require recolonisation of sites, presumably because this is a rare context in evolutionary terms in the region. In these circumstances the functional and species diversity of invasives is at its highest while that of natives is at its lowest. This result suggests exotics are less constrained in terms of recolonisation of disturbed habitats than natives, making them 'passengers' to disturbance rather than 'drivers' of native species loss (Murphy et al. 2006). Thus it is not surprising that Goosem (2003) states that land use, disturbance and climate are driving factors in weed invasion and that areas in rainforests that have been disturbed by humans, such as roads and power line clearings (Turton and Goosem 2003), are more susceptible to weed invasion than undisturbed rainforest and are the primary pathways for the introduction and dispersal of weed species into protected areas.

In the Australian Fisheries Habitat Review (1995) the authors reported that despite the importance to fisheries of coastal tropical wetlands there was a surprising lack of research on the environmental effects of aquatic weeds and pasture grasses. In a review of Queensland's wetlands, Lukacs and Pearson 1996, cited in AIMS 1995 concluded that even basic information such as the distribution, abundance and basic control options of aquatic weeds were non-existent and that studies of environmental impact of major weeds such as water hyacinth, salvinia and alligator weed were minimal. The research priority list developed by Bebawi et al. (2001) has since identified these and other species considered as major threats to the WTR, and projects such as the Ecology of WT Weeds undertaken by the DNRMW continue to fill gaps in the ecological knowledge of species including pond apple, hymenachne, siam weed, harungana, tobacco weed, sicklepod and hairy senna. Research is centred on aspects that are relevant to control strategies such as reproductive ability, seed viability and seed bank longevity, to maximise the effectiveness of management actions (Setter 2003). The short seed viability of pond apple has since been identified and might lead to long term control of the weed in the future (WTMA 2005). The Tropical Weeds Project undertaken by CSIRO Entomology includes the WT weeds: alligator weed, hyptis and mimosa and research includes their ecology and searching for suitable biocontrol agents for them.

A large amount of research has been devoted to searching for effective weed control including the development of herbicides, biocontrol agents (Julien 2002, Stanley et al. 2007) and integrated pest management approaches that combine a range of methods of weed control (Gould 2001, Paynter and Finnegan 2004, Coetzee et al. 2007). Considering the investment in biocontrol, there are few cases where it has been really successful, e.g. prickly pear (Dodd 1940), Paterson's curse (Nordblom et al. 2001), salvinia (Room et al. 1981), *Mimosa pigra, Salvinia molesta* and *Sida acuta* (Grace et al. 2006). Some introduced pasture grasses are considered unsuitable for biocontrol because of their value to the pastoral industry, despite causing significant environmental damage. Other weed species are considered unsuitable for biocontrol because they are targeted for eradication. But even if biocontrol itself is not successful, other benefits from the research involved include: research in to plant biology, integrated management and biocontrol and increased public awareness. Unfortunately, many biocontrol agents trialled have met with little success in the field. Despite this, economic analyses indicate that the return on investment in weed biocontrol in Queensland is high, at least $23.10 for every dollar invested (AEC Group 2005).

The role of genetics in helping to understand the dynamics of invasions has increased as methodologies and technology improve (Rollins et al. 2006, Delatte et al. 2006). It is now possible to determine:

- The number of genetically distinct populations represented in an invasion and the connectivity between them, providing an idea of whether eradication is possible (for small populations) or whether keeping plant numbers at low density is more feasible (for large populations or geographically widespread populations).
- Whether new seedlings post-control treatment are new incursions or remnants from the seedbank, and this can aid evaluation of the effectiveness of control programs.
- The origin of invasive individuals, which is useful post-control in identifying whether individuals are new introductions or whether they are remnants from the seed bank. Knowing the origin or native range of invasive individuals is also helpful in searching for their natural enemies which could be potential biocontrol agents.
- The number of separate introduction events, knowing where along the continuum of invasion (introduction, establishment or expansion) the species is helps focus control efforts.

Whilst genetics can be used to determine the effectiveness of control treatments (Rollins et al. 2006), by determining if an individual is new or left over from the seedbank, post-treatment, Regan et al. (2006) propose a different method of determining whether eradication has been successful or not. They state that eradication is often based on an arbitrary threshold of 1% or 5% confidence that the species is no longer present. Instead Regan et al. (2006) have developed a decision support tool that enables analysis of the decision trade-offs associated with how long to keep surveying to determine if a single species has been eradicated or not. They conclude that the optimal stopping time is a trade-off between the cost of continued surveying and the cost of escape and damage if eradication success is declared too soon, or the cost of continued surveys when the species is already eradicated. Given that the main defence against weeds includes continued surveillance and monitoring, the effectiveness of this decision support tool requires further testing, particularly for weed species growing in WT environmental conditions. Similarly, Smith et al. (1999) adapted a decision theory analysis of earthquake prediction to explore when it would be best advised to ignore the recommendations of a screening system for exotic introductions. In one scenario, they showed that a pest RA system with an accuracy of 85% would be better ignored, unless the damage caused by introducing a pest was eight times or more that caused by *not* introducing a harmless organism that was potentially useful. They conclude that in certain situations it may be more efficient to focus on identifying potential invaders from amongst already naturalised species than from amongst species at the importation stage, since the probability of successfully predicting which introduced species will become pests, is small.

The criterion used by Bebawi et al. (2001) that determined whether a species was a ‘search and destroy’ species or one that required further research is another invasive species issue that requires decision trade-offs. The costs of blind search and destroy are huge and the opportunities for improving it are inversely proportional to these. The potential to develop new methods to destroy weeds may also be limited and the decision to aim for partial control to keep the weeds at a density that is manageable may be what is required.

Research Needs

Some of these research needs were gleaned from reference to the scientific literature and may or may not have been addressed already.

Weed Risk Assessment and Prevention of Incursions

- Refined systems of risk assessment to identify species that pose threats to Australia's rainforests and associated ecosystems and to identify species with high impact potential.
- Develop a capacity to predict risk from sleeper species and candidate species.
- Develop effective measures to prevent introduction.
- Bioclimatic modelling for all species with the potential to invade WTR or that are currently present to predict potential range and habitat.
- Base-line biogeographic, life-history and ecological data from native and non-Australian invasive ranges of species that are present or have the potential to invade.
- Develop institutional and legislative approaches to limit the acquisition and introduction of new weeds within the WTR, e.g. identification of weedy species that cannot be imported or grown in the region.

Detecting and Managing New Invasions

- Develop monitoring and detections methodologies capable of detecting new incursions.

Understanding the Invasion Process

- Genetic and phylogeographic studies
  - to determine origin – useful to search for biocontrol agents
  - to track spread for identification of pathways and vectors of spread.
- Fill knowledge gaps on the basic life-history, population dynamics and autecology of current invasives under Australian rainforest conditions – e.g. age to reproduction, growth requirements, seed bank size and longevity.
- Identify the factors that facilitate weed invasions into rainforests.
- Identify the endogenous attributes of rainforests that place them at risk of invasion including the relationship between invasives and the plant functional groups present in rainforests.
- Description of dispersal and spread in rainforests and associated habitats
- Description of impacts on short and long-timeframes, including the ecological and contextual correlates and drivers of these.
- Understand the interactions between invasives and rainforest communities – influence of species diversity, functional group diversity, are there general patterns or are all invasions context specific?
- Impacts of climate change including i) changes in potential and actual distributions, and ii) changes in community structure and disturbance regimes that influence the ability of invasives to establish and spread.

Improving Weed Management

- Development of control methods, including:
  - Biological control.
  - Use of fire in rainforest and associated habitats.
  - Integrated approaches.
  - Seed bank control.

  - Ecological control.
- Surveillance and monitoring methods and development of new approaches to this.
- Assessment of costs and benefits weed control in rainforests.
- Assessment of effectiveness, sustainability of weed management.
- Non-target impacts of control.
- People – what are the methods for improving community attitudes to introduction and spread of invasives, involving communities in fighting rainforest weeds.
- Institutional arrangements to promote weed control.
- Factors influencing ecological-community impact.
- Develop priorities for weed management using criteria such as invasiveness distribution practicality and cost of control, means of dispersal and threats to WH values.

Aquatic Vertebrates

Species of Concern

The Wet Tropics bioregion has one of the highest levels of fish diversity in Australia and has many endemic species and species of high conservation value. More than 80 species are recognised from the region, including approximately 70% of the fish genera, and 45% of the fish species, in Australia (Pusey and Kennard 1994, 1996 plus unpubl. data, Rainforest CRC 2001). It is also a region with the highest aquatic invertebrate biodiversity in Australia (Pearson et al. 1986) and is amongst one of the highest in the world (R. Pearson pers. comm.). Hundreds, probably thousands, of invertebrate species remain undescribed and even new fish species are still being discovered. In addition to new species, recent genetic studies have shown that a number of the smaller species (e.g. rainbowfish, hardyheads, blue-eyes, purple-spotted gudgeons) consist of genetically discrete populations, forming evolutionary significant units. This is especially prevalent in streams where barriers such as waterfalls reproductively isolate populations.

Although the Wet Tropics as a whole has high fish diversity, unlike lowland streams which harbour many species, many individual upland streams are naturally depauperate in fish. This is because these streams have been isolated above waterfalls, which are common in the region. Most of these upland streams harbour only a few, generally small, fish, with eels, if present, being the only major predator. Because of the low fish diversity present, these streams have been subject to many fish introductions by persons wanting to develop a fishery resource. Often, the introduced fishes are large and predatory, as this provides a meat and sport fishery that is naturally lacking, though many translocated species are also unwanted aquarium species that have been released. Most of these fish are native to Australia, but when moved to waters where they do not naturally occur, are referred to as translocated native fishes. There is no automatic reason that translocated native fishes are less harmful than exotic fishes from overseas as the designations of native versus exotic are based on political, not ecological boundaries. The ecology of the fish in relation to the environment where it is introduced is more important in determining the nature and extent of impact, rather than where it came from.

The low fish diversity and low levels of fish predation are major natural features of these high value upland streams and many species and ecological processes have evolved in this environment. The fish-depauperate upland streams of the Wet Tropics are likely to be more susceptible to impacts of fish translocations than the lowland streams, especially because many of the aquatic species in the upland streams are likely to have limited or no tolerance to predation from novel fishes.

Although most of the fish introduced to the upland streams of the Wet Tropics are translocated Australian natives, the Wet Tropics have also been subject to introductions of exotic species. At least nine exotic species have been reported from the WTR, with six species successfully established in open waters (Table 12). There are at least 13 other non-native species reported from areas adjacent to the WTR (Webb 2003). Between 1994 and 2006, introductions in tropical northern Queensland increased by 90% and, without intervention, are likely to continue and at a faster rate.

Table 12. Exotic species of fishes reported within the WTR.

Common Name	Scientific Name	Established
Mozambique tilapia	*Oreochromis mossambicus* (hybrid)	Yes
Spotted tilapia	*Tilapia mariae*	Yes
Eastern gambusia	*Gambusia holbrooki*	Yes
Guppy	*Poecilia reticulata*	Yes
Platy	*Xiphophorus maculatus*	Yes
Swordtail	*Xiphophorus helleri*	Yes
American Flagtail	*Jordanella floridae*	No
Jewel cichlid	*Hemichromis guttatus*	No
Oscar	*Astronotus ocellatus*	No

Exotic and Ornamental Fishes

Most exotic fishes in the WTR have resulted from the release of ornamental aquarium fishes, though some, such as the Eastern gambusia, were introduced and deliberately spread by regulatory authorities to control mosquito populations (something they have not been especially effective at). The 'ornamental fish industry' in Australia includes traders, fish breeders, retail outlets and the hobby industry, and it is estimated to be worth $350 million a year (BRS 2007). Aquarium fish are popular pets, but when dumped or released into the wild, they can make their way into waterways and there pose a serious threat to the native aquatic biota and ecosystems. Limited historical knowledge of native stream fauna assemblages before the arrival of these exotic fish means it is difficult to quantify their environmental impact (Arthington and McKenzie 1997). However, there is sufficient evidence from studies elsewhere in their introduced range to demonstrate that some of these species (e.g. the tilapias and poeciliids) can have major adverse impacts on resident biota as resource competitors, predators or as vectors of pathogens. In addition, environmental impacts such as changes in water quality (turbidity, DO_2) may also have detrimental effects on the survivorship of native fishes (Burrows 2002). In degraded habitat where native fish populations, including piscivores, have declined, hardy invaders freed from competition and predation can proliferate and rapidly dominate communities. This is especially so in the WTR where exotic fishes (all of which occur in degraded habitats, urban streams or both) have been identified as current and future major threats to aquatic biodiversity (Burrows 2002, Harrison and Congdon 2002, Webb 2006, BRS 2007)

Although some control of exotic fish is already occurring, through quarantine regulations and State fishery regulations, there is no consistency between the regulatory frameworks and management strategies dealing with the issue of noxious aquatic pests (with the exception of European carp). Translocation of fish across borders freely occurs and little is known of which species are being traded, or the numbers of prohibited or noxious fish being bred and traded in the industry.

Despite several attempts to regulate the industry, success has not been achieved. This failure has been attributed mainly to lack of consultation and engagement with industry stakeholders. In order to address these issues, the Ornamental Fish Policy Working Group in close consultation with industry and other stakeholders, developed the *Strategic Approach to the Management of Ornamental Fish in Australia*, which has since been endorsed by the advisory committee supporting the NRM Standing Committee, the Marine and Coastal Committee, and is in the process of being implemented. The Strategy assesses the potential for aquarium fish to become pests and makes recommendations on managing and regulating their trade. Key recommendations include the need for a nationally recognised noxious species list, new management frameworks for the ornamental fish sector, better communication with stakeholders and a public awareness campaign on the dangers of releasing fish where they can get into waterways, and what to do with pet fish if they are no longer wanted (BRS 2007).

Many fish species in the trade are not on the current national permitted species lists established under Part 13A of the *EPBC Act 1999* or covered by quarantine regulations. It may be that such species have been permitted under previous statutory arrangements, but they are no longer on the list and are unlikely to have been assessed for their potential risk to the environment.

Burrows (2002) cites studies of introductions and translocations of exotic and native fish species in the USA, which have resulted in changes in ecology of waterways and have been associated with the decline in and extinction of local native fish fauna. The population declines have been due to two main factors which are also applicable to the WTR:

- The lack of predators of the introduced fish in their new environments, thus large numbers can be maintained in the new habitat.
- Native aquatic fauna have no defences against the introduced fish and become suitable prey.

The availability of suitable breeding conditions is also important.

Other effects of fish stocking (from Burrows 2002) include:

- Increase or decrease in birds feeding on fish.
- Increase in disturbance of waterbirds by recreational fishers in boats.
- Introduction or spread of aquatic weeds by the boats of recreational fishers.
- Increase in fish predation on tadpoles and invertebrates, such as prawns.
- Change in the behaviour of invertebrates such as prawns, to avoid fish predation.
- Change in the reproductive behaviour of frogs resulting in them breeding in sub-optimal conditions to avoid fish predation.
- Decline in the survival and growth rates of frogs and other native fauna.
- Competition with native species for food sources, space and habitat.
- Change in water quality through increased algal growth, as a result of predation on algae-eating invertebrates.
- Introduction of new diseases, pathogens and parasites that could affect amphibians, reptiles and other fish.
- In the WTR, removal of invertebrates that shred leaf litter could result in a decrease in the productivity of rainforest streams.

Native Translocated Fishes

The potential environmental impacts associated with translocation of native fishes in comparison to exotic fish species have received very little attention. Prior to 1986, translocations in the WTR were mostly done by private individuals and involved low numbers of fish, however since the state government (DPIF)-supported Recreational Fishing Enhancement Program (RFEP) and the development of mass hatchery techniques in the last 20 years, the number of fishes stocked has increased significantly (Burrows 2002). Burrows (2004) reported at least 36 native freshwater fishes have been translocated within the WTR and suggested that these fishes can have similar impacts as non-native fishes in waterways where they are stocked but are not indigenous i.e. did not previously occur. Many of these fish have been translocated above natural barriers, such as waterfalls, in the WTR, mainly to create recreational fisheries in these streams. Regardless of its provenance, a species moved beyond its natural range may cause significant environmental changes (Burrows 2002, 2004).

Over 30 million fish have now been stocked in Queensland under this program, including two million into waters of the WTR. Fish that do not naturally occur in the WTR also enter streams here after escape from farm dams and aquaculture facilities where they are commonly stocked, via release from aquaria, unofficial/illegal stockings by private individuals and official stockings by government fisheries agencies. Thirty-six freshwater fish species, plus red claw crayfish, have been translocated into waters of the WTR. Many of these translocations have resulted in non-local native species becoming established in the WTWHA (Burrows 2002).

Burrows (2002) reported that no environmental impact assessments for fish stocking had been undertaken in the WTR, despite the extensive stockings that have occurred, and the important faunal components of WTR streams that are considered to be vulnerable to predation by novel fish predators. He also reported that little was known of the distribution of translocated fishes within streams of the WTR, nor the extent of overlap between translocated fishes and potentially vulnerable species such as frogs and crustaceans.

Given the number of non-native fishes that are currently present or may be introduced in the near future, and the limited resources available to deal with them, it is imperative that these resources are strategically allocated to those species most likely to become invasive and create negative environmental, economic and social impacts. The process to identify these potential invaders is best done through risk assessment. Risk assessment for non-native fishes in Australian waters is still in an early phase (Burrows 2002).

Policy Framework

National

The importation of live fish into Australia is controlled at the national level by the DEH and Department of Agriculture, Fisheries and Forestry (DAFF) via AQIS, using the *EPBC Act* and the *Quarantine Act 1908.* Section 303 of the EPBC Act has a list of species approved for live import, if the species is not on it, then it cannot be legally imported (see DEH website), but a person can apply to amend the list and apply for approval after potential environmental impacts have been fully assessed. This process can take six to 12 months, depending on details of the case.

State

State and Territory legislation controls domestic breeding and the keeping and movement of ornamental fish. Depending on the jurisdiction it includes a prohibited species list and a permitted species list. The prohibited list does not seek to prevent trade in species where pest risk status is unknown and thus such species do not appear. Therefore fish that are not on the *EPBC Act* permitted import list can be owned and traded easily once they are here since their legal status is not specified in any legislation. Most fish smuggled into Australia are in this group and others are believed to have arrived before legislation came in to being. In most jurisdictions, the retail sector does not come under fisheries regulations and are only covered by industry codes of practice if they are voluntary members of the Pet Industry Association of Australia (PIAA). Inconsistency in legislation between jurisdictions enables movement of fish across borders. It is also difficult to identify species at all life stages on sight and therefore cryptic juvenile forms of prohibited species may get through undetected.

In Queensland, fish stocking and translocation of native fishes are regulated by the Freshwater Management Plan (1999) a subordinate regulation under the Fisheries Act. This plan lists legal size and bag limits, legal fishing methods and equipment, and other related matters. It also lists what species can be moved to what waters. This regulation for fish stocking is based on whole catchments, even though fish are not distributed throughout whole catchments. Thus if a species occurs in one part of a catchment, it is legal to release it into waters in another part of the catchment, even if it does not naturally occur there. This is especially relevant to the WTR where many streams have distinctly different communities above and below waterfalls. The Freshwater Management Plan is due for a major revision in 2008.

Regional

The prevention of new non-native species (species originating from beyond continental Australia), including freshwater fishes from establishing in the WTR is one of the priorities listed in the Conservation Strategy of the WTMA (1998).

Actions and Outcomes

Since the impacts of introduced exotic and native translocated fish and actions taken to manage them is similar, this section applies to all the pest fish species in general, rather than the individual species.

National

The Australian Government, through the Natural Heritage Trust Regional Competitive Component, contributed $910,000 to FNQNRM, the natural resources management body for the WTR, for a three-year project on integrated management of tilapia and other pest fishes in the WT. This project has four major components:

- Educating the public and raising their awareness of the severity of the problem in order to prevent further spread of pest species.
- Field surveys to determine the distribution of exotic and translocated fish species.
- Research into the impacts of tilapia.
- Begin integrating control measures in terms of methods for their control and integrated management plans.

This project is being led by the Australian Centre for Tropical Freshwater Research at James Cook University and includes all potential pest fish, native or exotic, although most effort is being deployed against tilapia. Further information is available on the project website (www.actfr.jcu.edu.au/Projects/Pestfish/Index.htm).

State

The Department of Primary Industries and Fisheries (DPIF) regulates and manages issues related to exotic fishes and translocation of native fishes, within Queensland. DPIF have a statewide Exotic Pest Fish Management Plan and employ a full-time exotic fish management officer. Within the WTR, they also conduct public education activities. These include dissemination of printed brochure material, inserts of pest fish pamphlets into rate notices, radio and television advertisements, public presentations and follow up on public reports of exotic fishes.

Regional

Other emerging pest species include grunters (sooty grunter, spangled perch and barred grunter are most commonly spread with the latter even being declared a noxious species in NSW due to its impacts there), climbing perch (*Anabas testudineus*) which have been moved by people from their native range in Indonesia to New Guinea and have recently been confirmed as present on Saibai Island in the Torres Strait (technically Australian territory), and a wide range of species from the aquarium trade, including three-spot gourami (*Trichogaster trichopterus*) which is rapidly spreading throughout the Burdekin-Haughton floodplain just south of Townsville, jewel cichlids (*Hemichromis* spp.), and Papua New Guinea rainbows (*Melanotaenia* spp).

In a report of the effects of fish stocking and translocated fishes in the WTR, Burrows (2002) made seven recommendations to WTMA which included:

- Documentation of where stocking of fish has occurred within the WT and consultation with WTMA before stockings that might 'impinge on WTWHA or its values'.
- Surveying to determine the distribution and abundance of stocked fish within important streams of the WTWHA.
- Environmental evaluation of existing stocking programs – impact of stocked fish on natural environments, e.g. Tinaroo, Copperlode, Koombooloomba Dams; a formal process for WTMA approval for any further fish stocking within the WTWHA.
- Audits of farms and aquaculture facilities to determine their roles in fish introductions.
- Greater involvement of WTMA in regulation and management of fish stocking.
- Development of fish stocking policy including native fish translocations, plus the indirect effects of increased fishing (e.g. more visitors, water quality, transfer of weeds) in WT management plan.
- Education program about potential translocation impacts, regulations/illegality of unauthorised stockings and inherent values of low, but high value, native fish diversity in upland WT streams.

A Memorandum of Understanding was signed between DPIF and WTMA addressing the issues raised in the report. As a result, there has been the transfer of WT fish stocking data from DPIF to WTMA showing the distribution of stocked fish in the WTR; fish stocking issues have been incorporated into WTWHA policy planning and development and notification and approval of planned fish stocking is now required. As yet, no audits of farm dams, which could be potential sources of exotic fish, have been undertaken (D. Burrows, pers. comm.).

Synthesis of Management Actions for Invasive Aquatic Vertebrates

Federal, State and Regional management strategies that have been developed all acknowledge that it is impossible to completely eradicate pest fish species from the waterways with current technology and aim instead to prevent new introductions and the further spread of the fish, and to reduce their environmental impacts on native biota and ecosystems. Attempts to control fish such as tilapia have been successful only in small localised waterbodies such as golf course ponds and farm dams and quarries. Most of the recommendations to WTMA by Burrows (2002) have been implemented and have raised awareness of the environmental impacts on the practice of fish stocking and translocation - matters which, prior to the report, had been ignored. They have also resulted in the transfer of information between management agencies.

Potential Future Threats and Capacity to Meet Them

Most of these species have not yet reached their full impact potential (Harrison and Congdon 2002). While the WTVPRAS indicates a high pest potential for these species it may still under estimate their possible future effects. This is primarily because of the lack of information on native fish species distributions, and the uncertainty regarding taxonomic status and levels of local endemism in the bioregion (Arthington and McKenzie 1997).

The two tilapia species pose the greatest immediate threat. This is because their large body mass enables them to dominate and exclude most native fish species while their ability to adjust metabolism and both their age and size at maturity to current resources enables them to maximise reproductive output under the environmental conditions they encounter (Arthington et al. 1999). In comparison, the smaller poeciliids do not overwhelm and modify habitat as quickly as tilapia are known to do (Arthington and Bluhdorn 1994, Pusey and Kennard 1994).

The limited thermal tolerances of Mozambique tilapia (Cnaani et al. 2000, cited in Harrison and Congdon 2002) may offer limited protection to catchment headwaters in the region. However, this species in the Cairns and Atherton Tablelands rivers (and now rapidly spreading throughout the Burdekin River system) is a hybrid and contains genes from two or three closely related oreochromids (*O. niloticus*, *O. aureus* and *O. honorum*) (Mather and Arthington 1991). Of these, *O. niloticus* has superior growth characteristics compared with *O. mossambicus,* and *O. aureus* is the most cold-tolerant oreochromid species. Hybrid vigour may enable this form to spread and dominate an even wider range of habitats than the 'pure' species that could parallel the spread of hybrid carp in the southern states in the 1970s. As yet, no detailed study on the ecological tolerances of this hybrid form has been done.

It should also be noted that populations of other exotic fish occur along the northern and central Queensland coast, principally in the Aplin Weir on the Ross River. These species include the green terror (*Aequidens rivulatus*), oscar (*Astronotus ocellatus*), red devil (*Amphilophus citrinellum*), banded cichlid (*Heros severum*), firemouth cichlid (*Thorichthys meek*i), Burton's haplochromis, *Haplochromis burtoni*, convict cichlid (*Archocentrus nigrofasciatum*), and pearl cichlid (*Geophagus brasiliensis*) (Arthington et al. 1999, Webb 2003).

The jewel cichlid (*Hemichromis bimaculatus(guttatus))* and oscars have been reported, but not established, in the Cairns area. Jewel cichlids have been observed in ornamental ponds in public gardens within the city and these ponds regularly overflow into stormwater channels following heavy rains (A. Webb, ACTFR, pers. comm.). These species exhibit very similar biology to the cichlid species already in the WTR and their risk assessments would produce similar conclusions. All these species have the potential to become major pests of the WTR.

In the MTSRF workshop held last year, the major future threats that were identified included:

- New aquatic diseases and parasites which could affect native species more than present invasive species.
- Pathways of introduction, e.g. ballast water, trade in aquatic organisms.
- The effects of climate change: changes in invisibility.
- Ability to detect and identify sleeper species.
- Economic effects of invasive species on commercial and recreational fishing, and water quality, whether they are seen as a resource or pest.
- Interaction between current and potential invasives on native species.

As there are few if any control methods, it must be concluded that the capacity to meet both current and future threats is seriously limited and investment in this area is needed.

Synthesis of Research Contributions to Management of Invasive Aquatic Vertebrates

Very little research has occurred on exotic or translocated fishes in the WTR, with most work consisting of surveys detecting the presence of species. Burrows (2002) provided a summary of the distribution of translocated native fishes in the WTR, based on literature searches and interviews with scientists and landholders. Much more detailed additional distributional information is currently being compiled under the FNQNRM/ACTFR NHT project, including additional field surveys. Although the scientific literature abounds with examples of impacts from translocated native fishes (see Burrows 2002 for a review), only very limited work has occurred on specific examples of their ecological impact in the Wet Tropics. Barlow et al. (1987) studied the loss of Lake Eacham rainbowfish from Lake Eacham, due to the introduction of native predatory mouth almighty. At the time, this was the only known locality of the Lake Eacham rainbowfish, so it was thought to be extinct in the wild. However, genetic analysis has since revealed its presence in other localities within the WTR, though the species remains on both state and federal endangered species lists. The story of fish translocation into Lake Eacham and other nearby crater lakes is summarised in Burrows (2002).

The direct and indirect effects of fish predation on frog tadpoles are recognised as one of the most important biotic factors influencing the composition of many frog communities. Many species also cannot coexist with predatory fish, confining their tadpoles to habitats where such fishes do not occur (e.g. upland streams, above waterfalls, in temporary pools). Burrows (2002) reviewed examples from Europe and North America of significant reductions and even localised extinction of frog populations after the introduction of novel fish predators. There have been similar reports from NSW of declines of rare and endangered frog species due to tadpole predation by eastern gambusia (Morgan and Buttemer 1996, Webb and Joss 1997, Pyke and White 2000). In the WTR, Fickling (1995) found that in tributary streams of the Tully River, *Litoria nannotis* and *L. rheocola* (both listed as 'Endangered' under the *EPBC Act 1999*) were restricted to streams without predatory fish, even though suitable habitat was present in the streams that contained predatory fish (primarily sooty grunter). Waterfalls provided a barrier that separated them with the fish occurring in the stream reaches below the waterfalls and the frogs in the stream reaches above the waterfalls. Movement of fishes above those waterfalls would likely lead to the loss of *L. nannotis* and *L. rheocola* in those streams. Three other frog species were able to coexist with fish predators in the same habitats through either unpalatability to the fish and/or ability to utilise microhabitats (e.g. riffles) that reduced predation rates upon tadpoles. In their review of the effects of introduced and translocated fish on Australian amphibians, Gillespie and Hero (1999) considered that the significant frog assemblages of the Wet Tropics would be at risk from introductions of novel fish species. They considered the stocking of high mountain streams to be of particular concern.

Genetic effects are also common in fish translocations through a variety of mechanisms. Translocations usually come from small numbers of individuals (maybe even a single parent) that establish a new population, resulting in a restricted genetic diversity. In the case of programs with regular stocking of large numbers of hatchery reared fish for the purposes of recreational fishing (e.g. into Lake Tinaroo), thousands of fingerlings are hatchery-reared and may come from a limited number of parents. Additional sources of impact can also result when individuals from one population are translocated into another. For example, rainbowfish occur in most WTR streams including upland streams but many populations have significant genetic differences. Translocations of rainbowfish from one stream to another can result in undesirable changes to the genetic structure of the receiving populations. Burrows (2002) provides many examples of genetic impacts resulting from fish translocations, including reference to issues in the WTR.

As for translocated native fishes, most research on exotic fishes in the WTR has revolved around detection of new species and determination of their distribution, with very little research on their impact. Mather and Arthington (1991) studied the genetics of tilapia populations in Queensland, including the WTR and Arthington (1991) provided an early review of impacts within Australia. Webb (2003) provides the most complete and up-to-date review of the status of exotic fishes in the WTR. There are many examples in the literature of the impact of exotic fishes, including eastern gambusia and tilapia. No studies, however, have examined tilapia impact in the WTR, though Webb (1994) and Webb (2003) demonstrated aspects of their impact within the Ross River system in Townsville. With funding from the Australian Invasive Animals CRC, DPIF are currently studying the reproductive biology of both tilapia species within the WTR with a view to developing population models. These can then be used as a first step in determining potential long-term population control measures.

Management agencies largely focus on prevention of new incursions of pest fishes, with public education being the predominant tool used. However, there is no research being undertaken into the effectiveness of previous or current public education programs. Similarly, the level of funding or other resources put into management of pest fishes often depends on the level of impact that can be demonstrated. There have been no studies into the economic or social impacts of translocated native or exotic fishes. Studies into the specific impacts of these fishes on the WTR are also limited, although there are abundant relevant examples from other locations within the literature.

Exotic fishes have, for many years, been accepted as being harmful and requiring management attention, though few management agency resources have been allocated to the task. The level of resource allocation has increased since 2005/06, though it still remains limited. In contrast, the issue of managing translocated native fishes was almost unheard of in many agencies until the review of Burrows (2002) which highlighted the disturbing level of modification of fish and aquatic communities that has resulted from such translocations in the WTR. DPIF have only regulated translocations of native fish since 1996 and for most other agencies, including resource managers and even aquatic scientists, this remained a limited issue until Burrows' review in 2002. Recent years have also seen an increase in research on the impacts of translocated native fishes, as the issue gains momentum in many countries, including Australia, and this is gradually being passed on in the form of greater government regulation and investigation of the issue. Despite this, the level of community awareness and acceptance of the impacts of translocating native fishes to new waters remains low.

The profile of exotic fish species is higher, both within the community and in government agencies, though most of this is focused on tilapia, with the many other exotic species present and those that may be introduced in the near future receiving negligible attention. Current research activities focus on delineating the distribution and habitat preferences of pest fish, demonstrating the degree and types of impacts from exotic and translocated fishes, and investigating methods to control the dominance of existing populations. Current research projects include the FNQNRM/ACTFR project focusing on distribution and impact of pest fish; a project investigating the use of sound in controlling tilapia (run by Oceanwatch via the FNQNRM/ACTFR project) and the Australian Invasive Animals CRC project run by DPIF.

Research Needs

Research gaps are focused around understanding the environmental, economic and social issues related to pest fish management, as well as developing methods for controlling existing populations and new incursions and improving management options.

Environmental Issues

- Document the distribution of pest fishes. Knowing the scale and scope of the issue remains a top priority and is a major focus of the FNQNRM/ACTFR project.
- From the distributional data, determine what stream and habitat types various pest fishes are most prevalent in. This prioritises the locations most afflicted by pest fish, and elucidates what habitat types are most likely to be affected. This analysis will also aid in determining how habitat factors can be used to control/limit the dominance of pest fish populations. For example, if the distributional analysis shows that pest fish such as tilapia prefer slow flowing, sandy bottom streams with open canopies, rather than high flowing, well-shaded first order streams, this prioritises control efforts.
- Determine impacts of tilapia on native aquatic fauna and ecosystems.
- Studies are needed to confirm the genetic identity and distribution of the hybrid form of *O. mossambicus* and define its ecological tolerance ranges. Based on morphological identification, this hybrid appears to be undergoing rapid range expansion and could pose a much greater threat than the 'pure' species, currently restricted to the Townsville-Thuringowa region.

Social and Economic Issues

- Undertake an assessment of the economic costs of pest fish. Assessing the true impact of pest fish requires that this evaluation be undertaken.
- Assess the impacts of pest fish upon social issues, including impacts of recreational fishing, ecotourism, people's perceptions of the values of wetlands (as many people will tend to place less importance on wetlands dominated by pest fish), impacts on indigenous values.
- As public education is the key to preventing new incursions and expansion of pest fish distribution, assessing the effectiveness of public education programs in getting their message across remains critical.

Management Issues

- Developing short-term control methods such as improved methods for detecting and capturing pest fishes and methods for removing small populations. This will improve the efficiency of monitoring programs and improve the likelihood of eradicating small, new incursions.
- Develop technologies for long-term population control of pest fish.
- Develop risk assessment protocols that allow for better prediction of potential likelihood of establishment and impact from potential pest fish species not yet present.

Invertebrate Pests

Another priority listing for invasive species are invertebrate pests. Historically, the invertebrate pests that have received most attention and resources have been those that can have serious impacts on primary industries and to a lesser extent, those that pose a threat to human health. Invertebrates that have the potential to cause serious environmental damage to ecosystems such as the WTR rainforests have generally been ignored and poorly resourced, thus little is known about them and their prevalence. Even estimates of economic impacts of invasive species fail to address environmental impacts and are focussed on costs to primary industry (Table 15), economic cost from Agtrans Research and Dawson 2005). However there is now a growing awareness of the importance of protecting ecosystem processes and services from invasive species.

According to Agtrans Research and Dawson (2005) there was no significant increase in the establishment of invertebrate pests of plants (presumably crop plants) in Australia between 1971 and 1995, although there were appearances of some new invertebrate pests, which have been contained or eradicated. However since then, increasing global travel and trade, and increasing instances of international yachts and illegal fishing vessels making landfall in northern Australia, have increased the likelihood of the introduction of new invertebrate pests to the country, for example, already termites, ants, borers, flies, earwigs, cockroaches, spiders, and stored-product beetles have been found on illegal vessels (NAQS 2005).

Invertebrates that are regarded as major environmental pests in the WTR include the crazy and electric ants (WTMA 2006, DPIF 2007a, 2007c, DNRW 2007c). Both of these ants belong to a group known as the 'tramp ants'. Ants within this group share genetic, behavioural and ecological characteristics that enhance their capacity to be successful and aggressive invaders with high environmental impact. These ants are known to disrupt ecosystem processes and services such as litter decomposition, pollination and seed dispersal by out-competing, predating on and displacing native invertebrate species (DEH 2006).

Outbreaks of both the yellow crazy ant (*Anoplolepis gracilipes*) and electric ant (*Wasmannia auropunctata*) were reported in Cairns suburbs between 2001 and 2007. These tramp ants are closely associated with and spread by people through the movement of infected plants and plant material (DNRW 2007b, DPIF 2007c). They can inflict painful stings and can significantly impact on peoples' health and outdoor activities (C of A 2006b). The outbreaks in Cairns were controlled through a coordinated approach by DNRMW, Cairns City Council, DPIF and EPA. The electric ant outbreaks were managed by specially trained electric ant eradication teams and an eradication program is being co-developed by DNRMW, DPIF and EPA (WTMA 2006).

Anoplolepis gracilipes is reported to have caused a catastrophic change in rainforest ecosystem processes on Christmas Island. By attacking and displacing the red land crab, a major consumer of leaf litter, seeds and seedlings, the ants have indirectly caused a greater accumulation of leaf litter and seedling recruitment has been disrupted (Green et al. 2004, cited in C of A 2006b). The crazy ants have also formed associations with honey-dew secreting scale insects which has caused an increase in canopy dieback and in some cases tree death (O'Dowd et al. 2003). In Queensland, this ant is a declared Class 1 animal pest, which means landowners must take reasonable steps to keep their properties free of the ant, and that it must be eradicated from the State.

Wasmannia auropunctata is known to be responsible for declines in invertebrate populations in Gabon (Walker 2006) ,New Caledonia (Le Breton et al. 2003, 2005), and the Galapagos (Lubin 1984, cited in Causton 2005), a decline in the hatching success of tortoises and birds on the Galápagos archipelago (Roque-Albelo et al. 2000, cited in Causton et al. 2005), is highly competitive for food sources and nesting sites (Le Breton et al. 2005), and can sting and cause blindness in domestic and native mammals (Wetterer and Porter 2003). Consequently, *W. auropunctata* is recorded as causing significant environmental damage on both continental (Walker 2006) and tropical island ecosystems (Le Breton et al. 2003, Wetterer and Porter 2003).

In 2006 a Threat Abatement Plan aimed at reducing the impact of six species of tramp ants on biodiversity in Australia was released (C of A 2006b, 2006d). These ants have become major environmental pests in overseas communities and have the potential to become the same in Australia (Table 13). Five of these species are regarded by the Invasive Species Specialist Group of the World Conservation Union (ISSG 2004) as being among the "World's One Hundred Worst Invaders" (C of A 2006); *W. auropunctata,* listed in Table 13, has been detected in Cairns in the past six years.

Table 13. The six list of national priority tramp ant species which are the focus of attention in the national TAP to reduce the impacts of tramp ants on Australia's biodiversity (Commonwealth of Australia 2006).

Scientific Name	Common Name
Solenopsis invicta	red imported fire ant
Solenopsis geminata	tropical fire ant
Wasmannia auropunctata	little fire ant
Pheidole megacephala	African big-headed ant
Anoplolepsis gracilipes	yellow crazy ant
Linepithema humile	Argentine ant

Another invertebrate species that is regarded by some as a pest is a biocontrol agent, the lantana bug, *Aconophora compressa*. This is a sap-sucking bug that was introduced in Australia in 1995 to control lantana (*Lantana camara*), a declared WoNS Weed of National Significance. *Aconophora compressa* is present in the WTR, but has had varying degrees of success. In Herberton and elsewhere the bug was found to attack exotic garden plants such as fiddlewood (*Citharexylum spinosum*), jacaranda (*Jacaranda mimosifolia*) and duranta (*Duranta erecta*), as well as lantana. It has also been found on at least five other species of native and exotic plants, four of which had higher densities of the bug than lantana (DNRW 2007a).

Policy Frameworks

Apart from the national TAP for the 'Reduction in Impacts of Tramp Ants on Biodiversity in Australia and its Territories' (C of A 2006b, 2006d), there are no formal policy frameworks that specifically address (environmental) invertebrate pests. The TAP provides a national framework for research and management of ants to prevent their further spread and reduce their impact on native species and ecological communities. It stresses the importance of community involvement throughout the whole invasion sequence as well as cooperation between all levels of federal, state, regional and local government management bodies (C of A 2006d). However, the TAP has not yet been implemented due to a lack of 'associated mechanisms for coordinating proactive management of the pests' and a lack of adequate resources from the Government to ensure implementation (Abbott 2007).

Actions and Outcomes

There is currently no institution that focuses on invertebrate pests that cause mainly social or environmental impacts (Agtrans Research and Dawson 2005).

National

Border quarantine procedures undertaken by AQIS involve surveillance and monitoring a distance of at least 400 m around all ports of entry for international vessels and at international airports within Australia. Larvae and adult insects are trapped and identified and international aircraft cabins and holds are sprayed to kill insects that transmit human diseases. AQIS officers also examine shipping containers and consignments for potential risk material.

In September 2001, the National Fire Ant Eradication Program (NFAEP) began in the Brisbane and Ipswich areas. It is a six year program with $175 million in funding from the federal government. It involves detecting and treating infestations of the red imported fire ant (*S. invicta*), minimising spread to new areas and monitoring and re-treating areas, if necessary. As at 2003, 98% of infestations that had been treated over the previous two year period were deemed to be fire ant free (DPIF 2005a).

State

A joint effort between Biosecurity Queensland, DPIF and the federal government has established the Hazard Site Surveillance Program, looking for 30 specific invertebrate pests and diseases of horticultural plants. Of these 30 pests and diseases, the ten most serious are listed in Table 14. The Program is targeting the Port of Brisbane, international airports and regional communities, however the list is not region-specific, so relevance to the WTR and perhaps other areas may be limited.

Table 14. Biosecurity Queensland's 'Top Ten Most Wanted List' of invertebrate pests and diseases in Queensland (DPIF 2007). It is not clear on what basis these species and diseases were listed apart from them having the potential to damage the horticultural industry, but they are being targeted by Biosecurity quarantine officers at all the major sea and airports of Queensland.

Common Name	Scientific Name
Red Banded Mango Caterpillar	*Deanolis sublimalis*
Citrus Canker	caused by *Xanthomonas axonopodis pathovar citri*
Giant African Snail	*Achatina fulica*
Red Imported Fire Ant	*Solenopsis invicta*
Glassy Winged Sharp Shooter	*Homalodisca coagulate*
Black Sigatoka	caused by *Mycosphaerella fijiensis*
Fire Blight	caused by *Erwinia amylovora*
Khapra beetle	*Trogoderma granarium*
Asian Gypsy Moth	*Lymantria dispar*
Eucalyptus Rust	*Puccinia psidii*

Since the unpredicted behaviour of the lantana bug has prompted some complaints from the public, DNRMW have undertaken further testing of the bug to find out why it has attacked fiddlewoods and other exotic plants. They have also developed a website providing information about the effects the bug has had on other plants, how to control it and how to treat affected plants (DNRMW 2007).

Regional

The DPIF and DNRMW have developed web sites that provide information about tramp ants and other invertebrate pests, their impacts and the control measures involved. The DPIF also operate the 'Northwatch' program which aims to detect and respond to outbreaks of exotic diseases and pests in north Queensland (DPIF 2007b). The program relies heavily on community involvement to report new sightings or outbreaks of invasive pests.

The NAQS is a section within AQIS, and operates across northern Australia, from Broome to Cairns. Its aim is to prevent the entry of exotic pests, weeds and diseases into Australia from countries to the north (Asia-Pacific). This involves 'identifying and evaluating quarantine risks to northern Australia and providing early detection and warning of new pests through scientific surveys, monitoring using traps for exotic insects, establishment of special quarantine areas and public awareness activities within Australia and in neighbouring countries' (DAFF 2007). NAQS has its own target lists of pests, diseases and weeds upon which to focus their survey efforts. However, the NAQS target list of invertebrate pests is focused on species such as Asian papaya fruit fly that cause damage to horticultural crops such as sugar cane, citrus and tropical fruit crops, rather than on environmental pests. As with Northwatch, it depends on local people to report new sightings or outbreaks of pests.

Local

To control electric ants at a local level, cooperation between the DPIF, NRMW and EPA resulted in the establishment of a dedicated Electric Ant Control Centre in Cairns and the development of an Electric Ant Eradication Program (EAEFP) (WTMA 2006). This Program involves:

- Identification of key infested areas, surveillance, treatment and control.
- Eradication and prevention of spread of known infestations through restricted movements of high risk materials from infected areas.
- Extension activities to provide information about the ants and control measures.

The Program also relies on members of the community to report sightings of target ants. Research and development includes development of new treatment methods, habitat modelling and controlled baiting programs (DPIF 2007).

At present the outbreaks of *A. gracilipes* and *W. auropunctata* have been contained and controlled within Cairns City and suburbs. The success of the control program has been due to the fact that the ants were detected early and eradication action was undertaken when the ants were in the early stages of invasion.

Synthesis of Management Actions for Invertebrate Pests

Concentrating on public awareness and appealing to the community to report any exotic pests to the appropriate agency have been important parts of the early detection of ants in the tramp ants control programs. Using this approach acknowledges that local people are out and about in more areas than staff in the management agencies can ever hope to be, and that a good understanding of the pest problem and ability on their part to identify pests can aid in detection. Early detection and then eradication is also the most cost-effective action to take. For example, in New Zealand an outbreak of fire ants was dealt with in the early stages of invasion and cost $1.38 m, whereas the delays in responding to the outbreaks of fire ants in Brisbane have resulted in an eradication program costing $175 m over six years (Biosecurity Australia 2005, cited in Olsen et al. 2006).

However, the well resourced and coordinated efforts between federal, state and local government agencies with the NFAEP and EAEP has so far resulted in containment of the outbreaks of tramp ants in the Brisbane and Cairns areas. The future success of this containment will be dependent on maintaining surveillance, follow-up treatment and monitoring of sites to ensure eradication success. The recent discovery of another infestation at Kewarra Beach suggests that these ants are easily and inadvertently spread through human activities. Thus, given the reactive nature of current management, the long-term containment of these ants will require a high level of public awareness and a commitment to monitoring.

Until adequate resources to implement the TAP research, training to increase expertise (such as training and employing ant taxonomists and ecologists) in Australia, and long term management strategies are developed and implemented, it appears that similar reactive strategies will continue. However the TAP has provided an overall view of possible methods of control. The tramp ants TAP acknowledges a lack of rigorous testing of toxins and baits against the full range of invasive tramp ant species (Stanley 2004, cited in DEH 2006). Three main approaches to control of invasive tramp ants include chemical, biological, and cultural control, with chemical control being the main management tool used (DEH 2006).

The risks and benefits of using biocontrol agents and thorough testing and risk assessments which include not only host specificity, but also ecological, climatic, spatial and temporal tolerances, must be weighed up objectively before committing to release of the agents. Although *A. compressa* was subject to screening on 62 different plant species, it was not tested on fiddlewood (DNRMW 2006). Normally this wouldn't be such an issue because this plant is itself an exotic species, but because it is also a relatively common garden plant and was attacked by *A. compressa*, it caused community concern. Studies have since shown that the climatic tolerance of *A. compressa*, does not spatially and temporally match that of lantana. This mis-match means that the insect will tend to look to other plants for food and thus its effectiveness in control of lantana Australia-wide, will be limited (Dhileepan et al. 2005).

Louda et al. (1997) reports of a biocontrol agent (weevil) that attacked an endangered native thistle plant instead of the weedy thistle that was endangering the native thistle and found that there had been inadequate testing before release. Other instances where risk assessment only included host specificity and had not accounted for ecological tolerances and environmental conditions are also reported (McEvoy and Coombs 2000). Since then retrospective ecological analyses (Louda et al. 2003, 2005) and ecological factors have been incorporated in to many risk assessments now undertaken.

Potential Future Threats

The possibility that there may be further outbreaks of tramp ants and other sleeper species that are not detected in the early stages, thus allowing them to become established in the region, remains a major threat now and into the future. To combat this, techniques for delimiting infestations and monitoring of adjacent areas are required. Early in 2007, Biosecurity Queensland released a list of invertebrates and diseases (Table 14) that could potentially have a significant impact on horticultural crops in Queensland, but their effect on natural ecosystems of the WTR such as rainforest communities is unknown, as is whether such species are already in the WTR.

Any one of the four additional tramp ant species (Table 13) could arrive and cause significant impacts on susceptible species such as reptiles and other native biota. Insects such as the European bee (*Apis mellifera*), Asian papaya fruit fly (*Bactrocera papayae*), spiralling white fly (*Aleurodicus dispersus*) and palm leaf beetle (*Brontispa longissima*) are also regarded as major pests in the WTR, although their greatest impact is on the horticultural and agricultural industries (DPIF 1995-2007), and they are already present in the region. Their environmental impact in the WTR is not known.

Whilst the European honey bee is valued for its honey production, it also impacts on native bees and a wide variety of birds and mammals through competition for tree hollows (Paton 1996) and for floral resources (NSW DECC). It can enhance the seed production of some native plants whose native pollinators have declined, but can also reduce the seed production of several predominantly bird-pollinated plants and compete with honey-eaters for nectar (Paton 1996, 2000). In China *Apis mellifera* has been known to out-compete the Chinese honey bee *Apis cerana*, resulting in a decrease in distribution and population of the Chinese bee and a reduction of total plant pollination and plant diversity (Yang 2005). In Australia *A. mellifera* is widespread, but is more likely to be found in eucalypt forests than rainforests (Paton 1996).

The Asian Papaya fruit fly (APFF) and spiralling white fly (SWF) pose huge threats to the horticultural industry in north Queensland. The APFF is known to attack twice as many fruit types as the Queensland fruit fly (DPIF 2005) while the SWF is a sap-sucking insect that causes black sooty mould to grow on leaves, resulting in decreased plant productivity or plant death (DPIF 2006). In Asia APFF inhabits rainforest areas and when first detected in Cairns in the early 1990s it was feared that it might also become established in WTR rainforests. This would have made eradication difficult but also carried with it the possibility that it might displace native fruit flies. While the APFF is present in the WTR rainforest it occurs in low densities and does not appear to have had any significant impact on rainforest fruits. Its effect on native fruit flies is unknown. Spiralling white fly occurs in the WTR, principally the Cairns area (Lambkin 1999). Although there are no reports of it being a pest in the rainforest (Defaveri, QDPIF, pers. comm.). Lambkin (1999) suggests that monitoring species of the Asteraceae, Euphorbiaceae, Fabaceae, Malvaceae, Moraceae and Solanaceae would provide a useful measure of its presence and impact. These families are well represented in the rainforest flora, however, the impact of spiralling white fly on them and on native invertebrate competitors is unknown. A parasitoid wasp is now successfully being used by the DPIF to control SPW in the northern tropics.

The Palm leaf beetle (PLB) has been identified as a serious emerging plant pest, one that is capable of killing small palms and weakening larger ones (DPIF 1995-2007). The PLB occurs throughout the Pacific Islands and northern Australia. It was first reported in the northern suburbs of Cairns in 1992. The movement of infected palms is the main mode of dispersal and despite local quarantine areas it has since spread south to Townsville and the Sunshine coast. The beetle is mainly a tropical pest affecting palms, however its climatic tolerance (DPIF 1995-2007) and its effect on palms in the WTR rainforest are not known.

Other potential invertebrate pests which may or may not be already present in the WTR include millipedes, Giant African land snails (listed in Table 7) and exotic earthworms.

The introduced millipede *Ommatoiulus moreletii* is well established as a significant pest in South Australia, Victoria, Tasmania and Western Australia where it has reached high densities and invades houses in large numbers at night in search of food (Baker 1985, McKillup 1988). Studies show that it is not competing with native millipedes in South Australia (Baker 1985) and that whilst it overlaps briefly in activity time and microhabitat with two native species of millipedes, there are no significant behavioural or ecological changes within the detritivorous millipede community (Griffin and Bull 1995). Its dispersal across Australia is associated with the transport of infested materials such as for building, or when people move house, so it is conceivable that they will eventually reach the WTR (if they are not already present). Based on the South Australian studies, it appears that their environmental impact might not be significant, but their potential impact in the WTR remains unknown.

The Giant African land snail was first detected in Australia at Gordonvale in 1977. The colony of snails was isolated and successfully eradicated over a period of eight months by the QDPI (Watson 1985). The snail is widely distributed throughout Asia and the Pacific. Its dispersal has been human-assisted: in cargo, by tourists and by people who regard it as a food source. It has the capacity to cause extensive damage to horticultural and agricultural crops, in high densities it can seriously affect outdoor activities such as lawn mowing and social amenity and it is known to harbour and transmit human diseases such as eosiniophilic meningitis and rat lungworm (Sturgeon 1971). Based on overseas experience, the snail has the potential to be a significant agricultural and environmental pest in the WTR, particularly since it is most likely to occur in areas with high rainfall, warm temperatures, calcareous soils and abundant organic matter.

Invasions of exotic earthworms and their capacity to significantly affect soil processes and plant communities are increasingly being reported worldwide (Hendrix 2006). Their dispersal has been assisted by the increase in global trade, both unintentionally, through the importation of soil-containing materials (agricultural and horticultural products) and intentionally, for use in commercial applications such as waste management and land remediation (Hendrix et al. 2006). Characteristics that may assist tropical earthworms in their invasiveness include high fecundity, continuous breeding and a short incubation period (González et al. 2006). Exotic earthworms are reported to cause significant changes to ecosystem function and processes, including modification of plant communities, changes in soil organisms, soil profiles, nutrient availability and plant productivity (Baker et al. 2006). Land use change such as clearing of rainforest for development or the conversion of rainforest to pasture can be a major factor in enhancing the establishment of exotic earthworms in the tropics (González et al. 2006). If this also holds for Australia, this is important in the WTR, particularly where urban development is adjacent to rainforest and where exotic earthworms may be introduced when people establish new gardens within rainforest.

Capacity to Meet Future Threats

Australia's capacity to deal with future invertebrate invasive threats appears to be somewhat patchy. The coordinated and well resourced responses to incursions of species with social and economic impact is encouraging. For example, the track record of federal, state and local authorities in successfully dealing with outbreaks of tramp ants indicates that Australia has significant capacity to deal with future threats if these are identified early enough. However, the near complete lack of research into the environmental impacts of invertebrate pests across the country, as well as in the WTR, means that we can only guess at these impacts and suggest that our capacity to detect and deal with them is as yet limited.

Current indications of capacity to meet future tramp ant invasions (and possibly other invertebrate invasions) are based on the success of current programs. These programs are well structured and are based around a response plan which includes risk assessment of the species, determination of possible introduction pathways and dispersal vectors, development of contingency plans, knowledge of current control techniques and technologies and a public awareness and engagement strategy. The response plan comprises three main phases:

- The trigger phase, which involves detection of the invasive species, notification of stakeholders and containment and movement controls.
- The scoping phase, which involves assessment of the scale and intensity of the problem and an environmental assessment of the response.
- The operational phase, in which action is taken and evaluated.

Eradication is the ideal goal, but only where it is feasible according to specific criteria; otherwise mitigation of impact is the objective. Progress is monitored throughout all phases in order to ensure all objectives are met. Evaluation of the effectiveness of treatments can thus be used to adapt to changing circumstances, including decisions for follow-up treatment and surveillance or a decision to stand-down (DEH 2006).

Continued monitoring and surveillance by Northwatch and AQIS at specified sites and at all ports appear to be the main actions that can be taken in ensuring early detection of invertebrates pests. Research into candidate species (those invertebrates that are pests in other countries with similar environmental conditions to the WTR) will ensure awareness and a degree of preparedness for their arrival.

The successful eradication of the Giant African land snail at Gordonvale was attributed to detecting it relatively early in its establishment phase (oldest snail estimated to be about two years old); it was found in a relatively small area (16 ha), plant quarantine and DPI authorities took immediate action involving intensive baitings and collections, and extensive media coverage encouraged community participation in identifying and reporting its occurrence and in cooperating with the eradication program. Maintaining public awareness programs about this snail was suggested as being essential to preventing it from becoming established in Australia (Watson 1985).

Capacity to meet other invertebrate invasives and particularly those of natural ecosystems is far less clear. In part this is dependent on our ability to: recognise them as invasives, determine their distribution and impacts, and implement effective control measures in rainforests and associated habitats. The poor state of invertebrate taxonomy and distribution in the WTR, knowledge of impacts, and monitoring that would pick up invertebrate invasives in natural systems, suggest that our capacity to meet future threats are limited. Also limiting are the will and the technologies to control invasive invertebrates. Despite listing invasive earthworms as a threatening process that impacts on the environment there has, to date, been no action to control or contain these invasions (K. McDonald, pers. comm.). While this may be due to a lack of will to manage the issue, it probably also reflects the difficulty of success of any program. González et al. (2006) suggest that the most sensible management strategy dealing with invasive exotic earthworms is to focus on their prevention and to study their invasions.

Synthesis of Research Contributions to Management of Invertebrate Pests

Blanche et al. (2002) focused on the relative importance of services (pollination and biocontrol) and dis-services (pests) provided by rainforest invertebrates to horticulture in the WTR, however there has been and is no current research of the environmental impacts of horticultural pests such as Asian Papaya fruit fly or spiraling whitefly in the WTR. Research into the effects of the introduced honeybee on native biota in Australia has been focused more on commercial outcomes than on environmental aspects, e.g. the impacts of commercial honeybees on the native flower-visiting fauna of Tasmania's leatherwood forests (Driessen 1998) and pollination of fruit crops in the WTR (Blanche et qal. 2002).

Research into the control of tramp ants has focused on developing effective poison baits (Fabres and Brown 1978, Wetterer and Porter 2003), as it is the most widely used method of control. Classical biocontrol was recommended to deal with large infestations by Wetterer and Porter (2003), however the tramp ants TAP (DEH 2006) notes that there are no examples of successful reduction in density and impact of any invasive ant following release of a control agent (Gilbert 2002, cited in DEH 2006).

In tropical regions, land use change is said to be a major factor in determining both the abundance and community structure of earthworms and in the establishment of exotic earthworms. González et al. (2006) propose that the introduction and establishment of exotic earthworms is positively related to disturbance, and that ultimately it can result in the competitive exclusion of the native earthworm species. However, Hendrix et al. (2006) concluded that exotic earthworms can invade ecosystems even in the absence of disturbance. They suggest that co-existence of native and exotic species appears to be common, though sometimes short lived, and that resistance to exotic earthworm invasions may be influenced more by the physical and chemical characteristics of habitat than by biological interactions between native and exotic species.

Resources for managing invasive invertebrates that are environmental and social pests have been lacking in comparison to those allocated to invertebrates that have the potential to affect primary industries. Our knowledge of the invertebrate ecology of the WTR is sufficiently limited that our ability to detect an invasion of natural ecosystems and to implement effective control strategies for many environmental invertebrate pests is generally lacking. Consequently, our current management strategies often rely on results from research undertaken overseas, an approach which risks non-transferability to the environmental conditions of the WTR. An exception to this may be the tramp ants which have been well-researched; however, a thorough understanding of their ecology has not necessarily aided implementation of the recommendations of the Tramp Ant TAP. Rather the barrier to implementation of the TAP has been a lack of resources and government support (Abbott 2007, Agtrans Research and Dawson 2005). The TAP provides a framework for research and management of the six tramp ants species that could potentially be serious invasive pests in Australia. It recommends research into:

- The environmental, economic, social and cultural impacts of tramp ants in Australia.
- Biology and ecology of tramp ants in Australia and overseas.
- Invasion dynamics.
- Pathways of dispersal and introduction.
- Identification of habitats most susceptible to invasion and potential distribution of the ants.

Drawing on research about the ecology and impacts of tramp ants in overseas places with similar climatic conditions and environments to the WTR has been useful in preparing management responses to outbreaks in Cairns and Brisbane.

Research Needs

Some of these research needs were gleaned from reference to the scientific literature and may or may not have been addressed already

Invertebrates Generally

- A description of the invertebrate biodiversity of the WTR, species' taxonomy, distribution, and community structure is fundamental to our ability to detect and identify environmental invasive invertebrates and to develop and implement management plans.
- Development of appropriate monitoring methods for detecting and delimiting invasions and assessing management success.
- Virtually nothing is known about environmental invertebrate pests in the WTR: their impacts, economic costs, effective management strategies, evaluations.
- Lack of capacity is a real problem in terms of enabling rapid identification of potential invertebrate pests (with Australian entomologists going overseas rather than staying in Australia) (Abbott 2007).

Earthworms (Gonzalez et al. 2006)

- Limited taxonomic knowledge of native earthworms in the WTR is complicated by the potential for loss of species in native habitats due to disturbance.
- Description of interactions between native and invasive earthworms in a range of contexts from undisturbed to highly disturbed, including the role of different functional types.
- Determination of the effects of earthworm communities of differing proportions of invasive species on soil physical and biogeochemical properties and overall ecosystem species composition.

Honeybees (Paton 1996)

- Quantify the (detrimental or not) effects of introduced honeybees on a diversity of native flora and flower-visiting fauna, with special consideration of spatial and temporal scale.

Tramp Ants (DEH 2006)

- Description of the basic biology and ecology of tramp ant species, including basic genetic, physiological, behavioural, and ecological attributes.
- Determine key factors for establishment, patterns of dispersal, and reproductive requirements of priority tramp ants.
- Improve surveillance and management of tramp ants, including community involvement in this, particularly on Indigenous-owned lands.
- Quantification of direct and indirect impacts, and the mechanisms of this impact, of tramp ants on biodiversity and other environmental, economic, health and cultural values.
- Review of known impacts of tramp ants, especially those species emerging as threats in the WTR.
- Assess environmental, economic and social costs of tramp ants.
- Description of invasion dynamics, including the identification of pathways of introduction and vectors of dispersal.

- Identification of habitats most susceptible to invasion by tramp ants and definition of their potential distribution.

Disease

The introduction of exotic diseases has the potential for dramatic impacts on WTR biodiversity and ecosystems. Past experience has been bleak. In one of the better documented examples of the impacts of introduced diseases on native biodiversity, avian malaria arrived in Hawaii with caged birds in the early part of the 20th century and was carried by mosquitoes. To date it has resulted in the decline or extinction of many species of endemic forest birds (Warner 1968, Jacobi and Atkinson 1995, van Riper et al. 2002). In the WTR forest dieback – attributed to the soil-borne pathogen *Phytophthora cinnamomi*, and frog chytrid fungus – caused by *Batrachochytrium dendrobatidis* in amphibians, have been the two major disease issues over the past couple of decades. These diseases resulted in widespread high mortality of plants and amphibians respectively during the initial stages of infection of previously uncontaminated areas and have provided us with our first clear glimpse of the potential impacts of exotic disease.

The potential for incursions of other exotic diseases of native plants and animals remains high, with those that have the potential for impacts on human health being among the most likely and most concerning. Vector-borne diseases such as avian influenza, dengue, Japanese encephalitis, malaria and West Nile Virus (WNV) all have host species with wild populations in the WTR and all have the potential to affect the human population living within the WTR. The mosquito, *Culex quinquefasciatus*, introduced into the Hawaiian Islands in 1826 (Warner 1968), is a potent vector of avian diseases, especially avian pox virus, *Poxvirus avium* and malaria, *Plasmodium relictum*. Feral pigs also are implicated in the distribution of the mosquito, and avian malaria, because their activities create larval habitat for the principle vector, *C. quinquefasciatus* (LaPointe 2006).

The same mosquito is believed to have been introduced to Australia with the arrival of Europeans. A survey of *Plasmodium* and *Haemoproteus* (a second protozoan cause of avian malaria) infection in tropical Australian birds showed high infection rates in 69 of 105 species, representing 44% of individuals surveyed (Beadell et al. 2004). Thus, these mosquito-borne diseases are present and potentially important limiting factors in the distribution and population dynamics of Wet Tropic birds. The role of *C. quinquefasciatus*, and the avian diseases it transmits, on the biota of the Wet Tropics is completely unknown. The potential impact of climate on the distribution of this disease vector and its potential impact on avian populations are being investigated by MTSRF Project 2.5ii3 (D. Hilbert, pers. comm.) and will not be discussed in detail in this report, nor will diseases of terrestrial and aquatic vertebrates affecting the primary industries since they are addressed by NAQS/AQIS, and DPIF's AUSVETPLAN and PLANTPLAN.

Policy Framework

Apart from the TAPs for *Phytophthora* and frog chytrid fungus, there do not appear to be any other formal policy arrangements at the national scale addressing the environmental diseases that affect WTR biota.

The North Australian Quarantine Strategy (NAQS) which operates across northern Australia, is primarily concerned with preventing the entry of exotic diseases from countries to the north which could affect the primary industries in Australia. However, with appropriate support it could also monitor diseases which might affect WTR wildlife and ecosystems. This would involve identifying and evaluating quarantine risks to northern Australia and providing early detection and warning of new pests and diseases through scientific surveys, monitoring, the establishment of special quarantine areas and public awareness activities within Australia and its neighbours (AQIS 2007).

Forest Dieback (*Phytophthora cinnamomi*)

P. cinnamomi was first reported in Queensland's tropical rainforests in the early 1970s (Brown 1976). It is believed to have been associated with forest dieback in southern Queensland as early as the mid-1960s. Although it isn't the only *Phytophthora* species detected in the WTR, *P. cinnammomi* appears to be the most virulent species present (S. Worboys, pers. comm.). Brown (1999) identified 11 species of *Phytophthora* in soil samples taken from dead rainforests at Dalrymple Heights on the Eungella Tableland, west of Mackay, and Garrawalt, northwest of Ingham, of which 86% were *P. cinnamomi.* Gadek and Worboys (2003) identified four species and one unknown species of *Phytophthora* in soils from survey sites within the WTR of which 45% were *P. cinnamomi,* and Worboys (2006) detected *Phytophthora* in eight of 27 samples taken from monitoring sites in the WTR, of which six were confirmed as *P. cinnamomi.*

In southern Australia *P. cinnamomi* has been responsible for high economic losses to forestry, horticulture and agriculture. In native plant communities it has caused changes in species composition, a reduction in plant species diversity (Weste et al. 2005) and indirectly reduced the populations of some animal species, including several regionally rare and nationally threatened fauna species (*Pseudomys fumeus* (endangered), *P. shortridgei* (vulnerable), *Isoodon obesulus* (endangered) (Wilson et al. 1994, Laidlaw 1997, cited in EA 2001) through the loss of habitat and food sources. Patches of dieback in WTR rainforest were detected in aerial photographs of the Tully Falls region in October 1999 (Pryce et al. 2002). Since then some 200 scattered patches of dieback have been mapped (Gadek et al. 2001) and studies have indicated that up to 14% of the WT WHA is susceptible to dieback, particularly in high altitude forests (Worboys 2006). Early studies showed that the disease has caused dramatic widespread plant deaths in the initial stages of infection, but subsequent work indicates that rainforest in some parts of the WTR has the ability to recover post-infection (Metcalfe and Bradford, unpublished).

Apart from the national TAPs relating to *P. cinnamomi,* chytridiomycosis and beak and feather disease there appear to be no other formal policies dealing with diseases that have an environmental impact.

Actions and Outcomes

National and State

In 2001 *P. cinnamomi* was identified as a key threatening process under the EPBC Act and a national TAP for 'Dieback caused by the root-rot fungus *Phytophthora cinnamomi*' was released. Its aim is to 'protect nationally listed threatened species and ecological communities from *P. cinnamomi* and reduce the further spread of the pathogen', however there are no references to the presence of *P. cinnamomi* in wet tropical rainforests and it is currently undergoing revision. Outbreaks in southern Australia affecting endangered species in reserves and National Parks have led to Tasmania, Victoria and Western Australia developing their own management strategies.

Regional and Local

Since *P. cinnamomi* was detected by Pryce et al. (2002) in the WTR, several studies investigating the distribution and ecological impacts of the pathogen within the WTR have been undertaken, leading to the implementation of precautionary control measures aimed at minimising further spread and the development of guidelines for monitoring vegetation recovery at dieback sites (Worboys 2006). Precautionary measures include strict hygiene protocols during maintenance work on Mt Bellenden Ker and disinfection of walking boots and other mud-bearing materials in highly susceptible areas and when working in remote uninfected areas of the WTR. Areas of high risk were identified and plans to restrict vehicular access developed. Long term monitoring to assess the recovery of rainforest, post-dieback is being undertaken by QPWS.

As yet, a lack of resources has meant there have been no assessments of whether the recommended precautionary hygiene protocols have been implemented or how effective they have been in reducing further spread of the disease, nor of the effectiveness of the TAP or of the information brochure.

Preliminary indications from long term monitoring surveys undertaken by QPWS suggest some recovery in infected areas. A possible reason for this is that trees stressed by drought of a couple of years ago were more susceptible to *Phytophthora*-related dieback, but are now recovering. Analysis of results from the surveys is still in progress (S. Worboys, pers. comm.). This finding would support the results of the long term study by Metcalfe and Bradford (unpubl.) which shows there has been a degree of recovery in some parts of the rainforest. Measurement of recovery (if any) on Mt Bartle Frere is expected to take several years due to damage from tropical cyclone Larry (S. Worboys, pers. comm.).

Frog Chytrid Fungus (*Batrachochytrium dendrobatidis*)

Frog chytrid fungus, *B. dendrobatidis*, causes chytridiomycosis, a disease that invades the skin of a range of amphibians (Santiago 2005) and can result in death. A seven year study of dead or ill amphibians from eastern Australia, between 1993-2000, revealed that chytridiomycosis was the most common disease in Australian amphibians (Berger et al. 2004, cited in DEH 2006). In the WTR, stream-dwelling species with small distributions and low fecundity are the species that are most impacted by the disease (Williams and Hero 1998). *B. dendrobatidis* has been linked with widespread amphibian population declines in eastern Australia, New Zealand, the USA, Panama, Ecuador, Venezuela and Spain (Berger et al. 1998). It has caused the extinction of at least four Australian frog species; one being the WTR endemic, the sharp-snouted day frog, *Taudactylus acutirostris*. Two additional WTR species (*Litoria nyakalensis and Litoria lorica*) were last recorded in 1990 and are suspected to be extinct. The disease has also caused the extirpation of three species of frog from upland WTR habitats (*Nyctimystes dayi, Litoria nannotis and L. rheocola*), although their lowland populations appear stable. McDonald et al. (2005) have observed some populations of frogs to have recovered post-infection and suggested that this may be due to increased resistance to the disease or a change in environmental conditions.

Actions and Outcomes

National

The importation of amphibians and their eggs into Australia is regulated by the Commonwealth departments: DAFF (for zoological facilities) and DEH (for laboratory purposes). Compliance with the Animal Biosecurity Policy Memorandum is required (ABPM) 2003/26; these require statements of origin of material, and its health and disease-free status.

Chytridiomycosis infection in amphibians was listed as a key threatening process under the *EPBC Act* and a national TAP to reduce the effects of chytridiomycosis on amphibians was developed in 2006 (C of A 2006a, 2006c). Its objective is to prevent the further spread of the disease within Australia, and to reduce its impact on those Australian amphibian species and populations that are already infected. It focuses on five main areas including preventing spread, promoting recovery, supporting research, supporting monitoring programs, and sharing information with stakeholders. This includes the quarantine and restriction of movement of amphibians from infected to uninfected areas, mapping the distribution of chytrid fungus in Australia, preparation of an action plan to deal with new outbreaks, introduction of a permit system requiring compliance with disinfection procedures to collect or work with flora, wildlife and amphibians, development and implementation of hygiene protocols for use in the field, laboratory and in industry, and strategies for promoting recovery by restocking infected areas with disease-resistant and uninfected captive-bred stock.

Many of the hygiene protocols recommended by the TAP were in place prior to the TAP (Speare et al. 2004) and are subject to review. A protocol for handling amphibians as part of field research is currently being drafted and will be attached to all frog scientific permits in future. It is based on the Amphibian Diseases Website and on information derived from JCU research and results of research by McDonald (K. McDonald, pers. comm.).

Regional

In response to the sudden decline of seven endangered frog species in the WTR, the Northern Queensland Threatened Frogs Recovery Team (NQTFRT) outlined a five year Recovery Plan (NQTFRT 2001) aiming to improve the conservation status and long-term survival of each of these species. The Plan outlined actions aimed at protecting existing populations and expanding their range, if possible, in previously occupied areas. It includes assessment and monitoring of populations, research on the disease, the reintroduction of species, dissemination of information and incorporation of frog issues in relevant land management decisions. The plan had an estimated total cost of $1.523 million.

Captive breeding programs of amphibians are already underway with protocols in place to keep them pathogen-free, as well as protocols to remove or decrease the risk of transmission of pathogens in the field (Speare et al. 2004) and in the laboratory. Speare (1999-present) established the Amphibian Disease Home Page website which provides comprehensive information about amphibian diseases, focusing on diseases of significance in wild populations and issues relating to handling frogs, preventing disease spread and data collection. It also has links to other related sites. This has been complemented with information brochures about the declines in frogs and their recovery plan and workshops dealing with the implementation of regular survey and monitoring programs of endangered frogs.

Local

Training of community volunteers and recruitment of members of the Tablelands Frog Club, Cape York Herpetological Society and WaterWatch has encouraged community participation in monitoring programs and surveillance of frogs in the field that has increased the capacity for species of concern to be identified and improved the likelihood of additional populations being located (Speare 1999). The Cairns Frog Hospital treats sick and injured frogs brought in by members of the public. It claims to have observed previously undescribed diseases in some frogs. The hospital is currently working with research institutions to identify and develop diagnostic tests for several of these diseases and has launched a project to map the distribution of diseased frogs that have been brought to the hospital in the past eight years (WTMA 2006).

Determining the current status of the disease remains difficult without monitoring of frog populations. Monitoring is currently underway. McDonald et al. (2005) report that at least one species, the green-eyed tree frog *Litoria genimaculata*, has recovered to pre-infection levels and suggest that the disease may be influenced by drier environmental conditions, such as those associated with El Niño. One of the endangered frogs featured in the NQTF Recovery Plan, the northern tinker frog *Taudactylus rheophilus* was thought to be extinct but was rediscovered in 1996, its current status is not known. Other frogs targeted in the recovery plan and thought to be extinct or extirpated have not been sighted.

Synthesis of Management Actions for Disease

Neither the implementation of management strategies for *P. cinnamomi* nor chytridiomycosis have been accompanied by a formal assessment of the efficacy of management. This could be due to a lack of resources (S. Worboys, pers. comm.) and the short period of time that the strategies have been in place (P. Gadek, pers. comm.). The precautionary hygiene protocols that have been implemented for walkers may have limited effect if *P. cinnamomi* is spread by forest animals whose movement is difficult to control. Ongoing monitoring of frog populations suggest that while some species have gone extinct or have been locally extirpated, other species have shown signs of recovery. Until the management strategies of both these diseases have been evaluated it is impossible to know if they have been effective in preventing the spread of the diseases and may be of limited use in guiding responses to future disease incursions. The NQTF Recovery Plan (NQTFRT 2001) included a set of milestones for the period 2000-2004 against which it could be reviewed and evaluated, however, there was no formal and complete review as such. Much of the work involved in developing the Recovery Plan was incorporated into the TAP to reduce the effects of chytridiomycosis on amphibians (C of A 2006a, 2006c), and has guided further research of chytrid fungus at JCU, and some of the results appear on the Amphibian Disease Home Page (Speare 1999-present) (K. McDonald, pers. comm.).

Potential Future Threats and Capacity to Meet Them

New incursions are the most likely future disease threats in the WTR. This requires movement of diseases, a process that can occur in a bewildering variety of ways. A primary mode of movement is via human activity. Increases in global trade, travel and migration between and within countries have brought with them an increased threat of new diseases being introduced, e.g. disease-carrying organisms in ballast water, infected organisms in cargo, or during the importation of live plants and animals for agriculture or the pet trade. However, natural (and therefore uncontrollable) processes can also play a role, e.g. the intercontinental dispersal of rust diseases on wind plumes (Aylor 2003). Similarly, long-distance, natural movements of organisms, e.g. migration or dispersal with water currents, can also provide effective dispersal for both environmental and economic diseases.

One of the main perceived threats is the possible arrival of diseases associated with migratory species, such as avian influenza and mosquito-borne diseases such as West Nile virus (WNV). WNV and avian malaria are potential and major threats to Australia's avifauna. Fortunately, WNV has not been detected here and avian malaria, whilst it has been detected here (Beadell et al. 2004), its effect or impact on native birdlife remains unknown. WNV has the potential to affect some mammals, especially horses and humans. Since its arrival in North America in 1999, WNV has spread across most of the continent, resulting in the deaths of more than 450 people and tens of thousands of birds, horses, and other animals (CDC 2003). By September 2003, at least 208 species of birds, 29 species of native and exotic mammals, one species of lizard and one species of alligator had exhibited WNV infection (USGS 2003). Mosquito species in the genus *Culex* appear to be the main vectors implicated in the avian cycle of WNV (Bernard et al. 2001) and *C. quinquefasciatus* is one of the principle vectors of avian malaria (LaPointe 2006).

Another disease of amphibians, ranaviral disease, is capable of causing high levels of mortality in wild and captive amphibians, however its role in Australian amphibian declines is unclear. It has been detected in cane toads *Bufo marinus* in NSW, Queensland and NT and antibodies against the disease have been found in freshwater tortoises in north Queensland. One of two endemic ranaviruses has been shown to be capable of infecting amphibians and, experimentally, has been shown to infect a number of native and introduced freshwater fish, freshwater turtles and snakes. Ranaviral disease affects amphibians to varying degrees.

The outcome is difficult to predict as the factors determining outcomes are unknown. Based on experimental trials and the epidemiology of ranaviruses overseas, there is the potential that a new ranavirus in Australia could cause local epidemics affecting small populations that are confined to small geographic areas (Speare 2001).

Highly pathogenic avian influenza (HPAI) or bird 'flu' is believed to have the ability to 'jump the species barrier' and infect humans, with the potential to cause a pandemic (AQIS 2005). It is an infectious disease caused by a virus and is found in wild bird populations. The sub-strain H5N1 has infected people as well as birds and been responsible for millions of bird deaths in Asia since 1997. The arrival of infected migratory birds is uncontrollable and, therefore, the introduction of the disease is a real possibility.

A National Action Plan to deal with future scenarios of avian influenza has been developed and quarantine officers from AQIS have been on 'high alert for bird products' at international mail centres and airports since late 2003, where they undertake thorough screening and inspection of flights, passengers, baggage and cargo. It is likely that the thoroughness of inspections may also increase the detection of other pests (AQIS 2006). Continued surveillance and monitoring by AQIS, NAQS and communities in northern Australia, encouragement of all industries (fruit, vegetable and nursery) to reduce or eliminate the risk of translocating amphibians (Speare 2001), implementation and review of strict hygiene protocols when handling amphibians in the field and laboratory (Speare 2001), as well as collaboration with neighbouring countries, appear to be essential for early detection of any potential pests or diseases.

Also of concern, and more difficult to control, are illegal fishing vessels and international yachts that make landfall without going through any quarantine inspections. A range of insects, animals, birds and food products that can harbour disease or become pests themselves, have been found in such situations (NAQS website).

Synthesis of Research Contributions to Management of Diseases

The primary aim of research into *P. cinnamomi* has been to identify and describe the issue at hand. It has shown that there is a link between *P. cinnamomi* and forest dieback in the WTR in the majority of cases (Worboys 2006), though at least five other species of *Phytophthora* have been identified at infected sites. Until recently, very little was known of the biology, ecology and dynamics of *P. cinnamomi* in Australian wet tropical rainforests. Indeed it is unclear how long *P. cinnamomi* has been present in the WTR. The fact that it appears to be widespread in the region and can be present for decades in apparently healthy forests with no noticeable impact suggests a long presence (EA 2001, Pryce et al. 2002).

It is still not known what triggers outbreaks of dieback in the WTR, although rainfall is required for dispersal (Gadek 1999). Outbreaks have been associated with human disturbances which affect the hydrology of an area. Examples include road construction which causes water to collect to the side of the road, logging which causes an increase in soil moisture due to a decrease in transpiration and feral pigs whose wallows collect water and the pigs also have the potential to transport infected soil (Brown 1976). Without disturbance, *P. cinnamomi* requires free water for dispersal and persists in soil for very long periods of time. It can also be dispersed in infected soil. Anecdotal evidence suggests that animals that disturb the soil as part of their foraging, e.g. feral pigs (Brown 1976, Tisdell 1982, Worboys 2006), bandicoots (*Isoodon macrurus*) and orange-footed scrub fowl (*Megapodius reinwardt*) (Metcalfe and Bradford, unpubl.), are possible animal dispersers of the disease in the WTR. Outbreaks at two mountain sites have been associated with walking tracks and pig damage (Worboys 2006).

Mapping of the distribution of outbreaks of dieback from aerial photographs (Gadek et al. 2001) and on-ground assessments have helped identify the areas within the WTR that are most susceptible to the disease (Worboys 2006). These are primarily the high altitude mountain forests such as at Mts Bellenden Ker and Bartle Frere, the Carbine Tableland and Thorntons Peak and upland/highland forests (Worboys 2006). In these areas plants from seven families have been observed to be susceptible to infection (Brown 1999, Guest 1999, Worboys and Gadek 2004, Metcalfe and Bradford, unpubl.), including several listed threatened species and some rare endemic species from Mt Bartle Frere such as: *Cinnamomum propinquum*, *Rhododendron lochiae, Eucryphia moorei*, *Dracophyllum sayeri* and *Leucopogon malayanus* (Worboys 2006). The high altitude forests on Mts Bellenden Ker and Bartle Frere, in particular, have since become the focus of long term monitoring.

Cahill and Hardham (cited in Gadek 1999) state that *P. cinnamomi* has strong genetic, biochemical and structural similarities to some algal and protozoan organisms and therefore is not a fungus as previously thought. Gadek (1999) suggests that this means that the approach to managing the disease may need to change. Worboys and Gadek (2004) proposed a list of tree species that could be used as indicators of the presence of *P. cinnamomi* in the WTR, but the findings of Metcalfe and Bradford (unpubl.) did not support this completely, leading to the conclusion that variation in pathogen virulence or host susceptibility or both, may vary, suggesting that more research would be required before trees could be confirmed as reliable indicators.

Based on knowledge that the disease could be spread in infected soil and that outbreaks have been associated with disturbance that affects hydrology of an area, hygiene protocols for forest users such as disinfection of footwear and machinery and quarantine of infected plant material and soil have been recommended, the drainage of walking and vehicle tracks was planned and gates installed on priority roads to restrict access when conditions are unsuitable for traffic (Worboys 2006). However there has been little, if any, evaluation of the effectiveness of these hygiene protocols, or knowledge of how widely they have been implemented within the WTR.

Evidence that wet tropical rainforest is able to recover from outbreaks of this fungus suggests that while the initial impact of *P. cinnamomi* infection may be dramatic, it decreases over time and it is possible that recruitment can be greater than pre-infection (Metcalfe and Bradford, unpubl.). Their observation of recovery post-infection is similar to that observed by Weste and Ashton (1994) in the Brisbane Ranges, Victoria.

Reseach on chytridiomycosis has contributed to understanding and management of the disease. The current epidemiological model is that chytridiomycosis is an emerging infectious disease that has spread globally (Daszak et al. 1999, 2003). It has the potential to cause an epidemic wave of high mortality on initial introduction to a previously uninfected area, and then becomes established, acting as an endemic pathogen interacting with local amphibians. The severity of its prevalence is affected by season and altitude, being more prevalent in winter and above 300 m in altitude (McDonald et al. 2005). Analyses of endemic rainforest frogs that have declined indicates that all were characterised by the combination of low fecundity a high degree of habitat specialisation and reproduction in fast flowing streams (Williams and Hero 1998). These characteristics may be particular to affected frogs in the WTR as they are not the same for susceptible species elsewhere in Australia (Mahoney 1999, cited in NQTFRT 2001).

Three WTR frogs have become locally extinct from higher altitudes, three species are regarded as extinct and one surviving species of stream-dwelling frog *L. genimaculata* increased in number to pre-infection levels, indicating a change in pathogen-host relationship. Results (K. McDonald, pers. comm.) support the proposal that a change in environmental conditions that favour the host, such as lower rainfall associated with the El

Niño weather pattern, may be responsible (McDonald et al. 2005). Preliminary results of joint studies between JCU and QPWS looking at the distribution of frog chytrid fungus in the WTR and Cape York Peninsula, indicate that frog populations from open forests do not have the fungus, that it has not invaded banana plantations of the WT lowlands and that not all rainforest frogs are affected (K. McDonald, pers. comm.). Researchers at JCU are investigating the dynamics and disease transmission in the wild, in a range of habitats throughout the WTR, including why some species are more affected than others.

The findings of McDonald et al. (2005) that some frog species can survive chytridiomycosis, and that its prevalence can decrease over a relatively short period of time, provide support for assisting susceptible amphibian species to survive an initial epidemic wave of chytridiomycosis by ensuring some breeding stock survive the initial epidemic wave and are bred in captivity or in the wild, for selected resistance to the disease to restock. Frog research results so far have not led to any management actions and based on current knowledge, it appears the disease is now endemic, with no present means of eliminating it from the WTR (K. McDonald, pers. comm.).

Research Needs

Some of these research needs were gleaned from reference to the scientific literature and may or may not have been addressed already

General

- Risk assessment of diseases generally and to specific diseases is hampered by our limited knowledge of disease in wild populations generally, and our almost complete lack of information for disease in WTR ecosystems specifically. In the case of arthropod borne diseases of wildlife, including avian malaria and various viruses, we need to know how these endemic diseases influence vertebrate distributions and densities and how continuing climate change may affect their distributions and morbidity.
- Research into the prevalence and impact of disease in populations of native species would provide context for making assessments of both the nature and severity of the risk posed but also the potential and means by this kind of risk can be managed both pre and post-incursion.
- Review of environmental diseases and their impacts from elsewhere,
    - e.g. WNV and ranaviruses that represent potential threats to WTR ecosystems, their likely pathways and vectors of introductions and potential management options.
- Development of effective detection and monitoring methodologies for key classes of disease threat.
- Development of emergency response measures for major classes of disease threat.

Phytophthora (DEH 2001)

- A process of evaluation of the hygiene protocols and management strategies implemented to reduce spread of *P. cinnamomi* in the WTR rainforest is required to assess whether they have been successful.
- Molecular phylogenetics could be used to identify and detect *Phytophthora* species in soil and plant tissue in the WTR.
- Genetic diversity studies could be used to determine the historical spread of *P. cinnamomi* in the WTR and place it in context with species from other places within Australia and overseas (Gadek 1999).
- Establish monitoring studies in the WTR of sufficient duration to determine the:
    - long term impacts of the pathogen, direct and indirect;

  - effectiveness of management measures in different environments and with different susceptible species.
- Identify areas of high conservation value within the WTR where *P. cinnamomi* could become established and assess the level of risk of the pathogen spreading to and infecting plant populations in these areas.
- Identify potential routes of spread from currently infected areas to the nominated areas having a high conservation value and limit the vectored dispersal into these uninfected areas.

B. dendrobatidis and amphibians (DEH 2006, Speare 2001)

- A process of evaluation of the hygiene protocols and management strategies implemented to reduce spread of *B. dendrobatidis* in the WTR rainforest is required to assess whether they have been successful or not.
- Evaluate effectiveness of habitat manipulation to improve environmental suitability or general amphibian well-being, in chronically infected amphibian populations in the WTR.
- Investigate the separate effects of temperature and altitude on mortality and infection rate from *B. dendrobatidis* in WTR amphibians (McDonald et al. 2005).
- Knowledge of the prevalence expected in endemically-infected amphibian populations is important in guiding design of wide-scale survey protocols to determine the amphibian chytrid-status of regions and countries (Speare 2001).
- Research and document frog declines in other WTR ecosystems besides rainforest (NQTFRT 2001).
- Develop survey protocols for comparative studies between chytrid-infected and chytrid-free areas.
- Examine the effects of chemical composition of natural water bodies and environmental conditions on the biology and survival of *B. dendrobatidis.*
- Investigate how *B. dendrobatidis* is dispersed between water bodies.
- Determine whether cane toads can be vectors of chytridiomycosis and whether infection is related to their presence or distribution.
- Investigate surviving robust populations of species and determine what factors enable them to survive and whether they are susceptible to future infection.
- Collaborate with industry (tropical fruits, vegetable, nursery industry) at local, state and national level to determine the critical control points where frogs enter products and where they can be most effectively removed and set a defined standard for each product of each industry to meet 'ecofriendly' criteria that minimise the number of frogs moved with produce.
- Quantify the involvement of each industry in accidental translocation of amphibians in and out of the WTR.
- Assess the risk to local amphibians from accidentally translocated frogs, including disease status and the current status of chytridiomycosis and ranaviral disease in amphibians.
- Develop a hierarchy of risk using the conservation status of species at sites and the status of chytridiomycosis and ranaviral disease at sites. This could then be used to minimise spread and potential impacts of the pathogens.
- Increase understanding of the epidemiology of ranaviruses in wild amphibians in the WTR.
- Determine the potential of foreign ranaviruses and those intercepted in imported fish and reptiles to cause disease in WTR amphibians.
- Determine the environmental factors that influence the pathological outcome of the disease.

Economic Costs of Pest Control

Information about the cost of invasive species control and management implementation is often difficult to obtain since it is either not collated, is hidden in grey literature, or is for internal departmental access only. In a review of progress on invasive species management, Agtrans Research and Dawson (2005) reported that there was inadequate knowledge of what resources were invested in invasive species programs as a whole. Of the few reported cases attempted, often the data is inconsistent or incomplete in that the environmental and social costs and the costs to industries other than primary industry, e.g. the tourism industry, are excluded (Table 15). It was also noted that the economic impacts of invasive species include both costs and benefits, but benefits such as a weed species providing habitat for native animals, or are not usually acknowledged. This means that the limitations on the results are severe since conclusions are inaccurate and it is difficult to compare the data over time and between locations.

Table 15. Summary of economic impact estimates for invasive species. The figures are estimates only and are not based on published material; they also exclude environmental and social costs, and costs to industries that are not primary industry, they also do not include the indirect cost of control, nor trends in costs over time (from Agtrans Research and Dawson 2005).

Invasive Species Group	Economic Impact Reported	Costs and Benefits not included
Weeds	$4.1 billion	Costs and benefits to the environment such as biodiversity, social impacts such as human health costs. Benefits from weeds not included, e.g. Benefits to the bee industry.
Pest animals - Vertebrates	$0.72 billion including some environmental costs	Social impacts such as human health costs and most environmental impacts not included. Benefits from pests not included, e.g. Sale of goats.
Plant diseases and invertebrate pests of plants	At least $0.70 billion per annum. Total is likely to be a multiple of this figure, perhaps at least $2 billion per annum.	$0.70 billion based on studies for wheat, sugar, two horticultural crops, sunflowers, and cotton. Excluded from the $0.70 billion are diseases and invertebrate pests of pastures, nearly all of horticulture, all other grains, cotton, forestry etc. Also excluded are environmental and social impacts. $2 billion estimate made from loss estimate of 7.5% of the $17m average gross value of plant industries plus fungicides and insecticides sales of about $0.5m plus application costs.
Animal diseases and invertebrate pests of animals	At least $1.2 billion per annum	Based on production loss of 5% of a $16 billion per annum animal industry plus value of animal health product sales. Excluded are diseases and invertebrate pest impacts on the environment.
Other invertebrate pests	No estimates identified or made.	

An additional constraint on estimating the costs of invasives is the difficulty of identifying a consistent currency, since not all impacts are on values that are readily measured in dollar terms. Translating the cost of environmental or social impacts into monetary value is difficult because methods of placing a monetary figure on values such as ecosystem services or processes produce highly variable results.

Norris et al. (2005) estimate that using current methodologies to translating environmental damage into monetary terms would require significant investiment (possibly hundreds of thousands of dollars) and that the lack of biophysical data about invasive species is a major limiting factor valuation of the environmental damage they cause.

Pimentel et al. (2000) estimate that non-indigenous species (plants, vertebrates, invertebrates, molluscs and microbes) in the USA cause over $137 billion of environmental damage and loss per year. This estimated cost is based on the combined costs of control and production losses and public health costs. These authors acknowledge that this an underestimate of true environmental damage since a monetary value is not available for species extinction or loss of ecosystem services. However the cost of bird predation by cats was determined by an estimate of how much a birdwatcher spends on observing a bird, how much a hunter spends per bird they shoot and how much ornithologists spend per bird reared for release. In other words, the loss of birds to predation was valued by the cost of their presence or amenity to humans. Alternative ways of measuring environmental impacts (on ecosystem services and processes) by invasive animals include estimating the potential benefits of a particular management action, applying a probability factor of success and then calculating the cost of the action (Taylor and Edwards 2005) or determining the number of native species lost or near extinction (Norris et al. 2005). The problem with the latter suggestion is that loss of species is not always directly related to the presence of an invasive species.

A nation-wide survey of the costs of pest animal (foxes, wild dogs, feral cats, feral pigs, goats and rabbits) control and monitoring operations undertaken by conservation-focused organisations in Australia between 1998-2003, determined that foxes and rabbit were the most frequently controlled and cats the least frequently controlled and that annual labour costs of control were estimated to range between $30,000 and $1 m for feral cat control and between $1.8m and $5.3 m for fox control. However it was difficult to determine the relative cost-effectiveness of different control methods used (Reddiex et al. 2006), possibly because of the large number of techniques used and the large scale of the survey. In contrast, Mitchell and Dorney (2002) determined that feral pig trapping by landowners on cane and banana farms in north Queensland, was the most effective method from a range of control methods available.

Estimates of the cost of all invasives to Australia have not been attempted. Sinden et al. (2005) attempted to estimate the cost of weed control in Australia to the natural environment (defined as National Parks and other areas listed as 'natural' in agreements on the use of NHT funds). But due to lack of available and consistent data on the effects of weeds on the provision of goods and services from natural environments and no market-based prices for the values of these outputs, they were only able to determine the direct costs (herbicide, labour and contractor costs and other materials) of weed control, which in 2001-2 was $19.6m. This calculation is also acknowledged as being an underestimate of the true cost as it excludes the indirect costs such as mapping and surveillance of weeds and depreciation of equipment; the value of thousands of volunteer hours, the health effects of pollen from weeds and the value of the ecosystem services that are affected by weed invasions.

In Queensland, the average annual expenditure over an eight year period to 2002-03 on declared weed and pest animal management across Queensland, was $10.2 million by DNRMW and $12 million by local government (AEC Group/LGAQ 2002). In 2005/6 the total estimated expenditure on weed and pest animal management by local (based on 20 Qld local governments) and State government and regional NRM bodies for which data was available was $46 million and has increased on average by 6.9% p.a. since 1994/5 in real terms. This annual percentage increase relates to State government expenditure through DRNMW only, but the 2005/6 figure includes expenditure by Main Roads, QPWS and Queensland Rail (AEC Group Ltd 2006). Again, these figures are only direct costs of control.

The main components of weed and pest animal management and control include prevention, eradication, containment, research and education and awareness. An analysis of the return on investment for each of these weed and pest animal management components, based on

Queensland case studies (AEC Group Limited 2006), showed that the return on investment was greatest for prevention and least for control (Table 16). Thus there is a strong incentive for taking measures to prevent the introduction of an invasive species, or eradicating it whilst it is in the earliest phases of establishment and before it becomes widespread. For example, the early recognition, reporting and control of *C. odorata* in Queensland, represents a possible saving of millions of dollars annually (in the long term) and means that, although complete eradication from the WTR is still expected to be some years away (Setter and Vitelli 2003), in the short term, this species is unlikely to become a major pest in the WTR (Waterhouse 2003).

Table 16. A comparison of the returns on investment for the five main management actions dealing with weed and pest animal management, based on case studies within Queensland (AEC Limited 2006).

Management action	Return on investment for every dollar invested	Case study
Prevention	$26.60-$38.30	Impact of a number of the most likely weed and pest animal species to invade Queensland
Eradication	$9.90-$26.80	Siam weed (*Chromolaena odorata*)
Control	$1.70-$3.10	SWEEP programs: prickly acacia *Acacia nilotica*, rubber vine *Cryptostegia grandiflora* and mesquite Prosopsis spp.
Research	$13.90-$24.40	Biocontrol of parthenium *Parthenium hysterophorus*
Education and awareness	$8.00-$79.70	Weedbuster program
Control of Environmental weeds	$1.10-1.80	Control and management of environmental weeds in south-east Queensland

In a benefit-cost analysis of weed biocontrol programs that have been undertaken in Australia, Page and Lacey (2006) determined that the return for every dollar invested in biocontrol in 2004-5 dollars was $23.10. This was based on all weed biocontrol programs for which economic data was available, however, it is not clear as to whether costs such as the cost of biocontrol agents that fail to become established or the cost of biocontrol agents that attack non-target species instead of the target species were included in the analysis. If not, then the true return may be different. It was also found that many biocontrol programs which were considered to have been successful, had to be excluded from the analysis because of the lack of data quantifying the benefits of the program. The exclusion was not an indication of failure of the projects, but the lack of performance indicators meant that they could not be evaluated. Thus, the overall benefit-cost results may not reflect the true benefit-cost of biocontrol programs. To overcome these issues, Page and Lacey (2006) recommended that:

- Future biocontrol programs publish an environmental impact and distribution data about the target weed species prior to release of biocontrol agents.
- Research costs be recorded for future analysis.
- Monitoring and evaluation of progress be undertaken throughout the program and after release of agents, including the economic impact of the target weed after establishment of biocontrol.

- Environmental and social impacts of biocontrol programs be measured, such as the impact of the target weed on native biodiversity and the cost of removing the weed from sites of high environmental value.

These recommendations are not specific to biocontrol programs, they are applicable to all invasive species control programs. By collecting this data, and incorporating social and environmental impacts into such programs, evaluation and management decisions are then possible to make the best use of resources.

An analysis of the benefits of weed research and returns on investment in the Invasive Plants CRC (IP CRC) (benefits spread over a 25 year period and converted into a present day monetary value) estimated for every dollar invested in the IP CRC, $55 would be returned to the primary industries (beef, lamb, wool and cropping) and the wider economy. The relatively large BCR reflects the sized of the weed problem in Australia, the increases in productivity occurring in agriculture and the short time required for biological responses to new technology in weed research (Jones et al. 2006). Unfortunately the report did not include any analysis of benefits specifically to the environment.

Research Summary

Strategies for Invasive Species Research

As with any question about a complex phenomenon there are multiple levels and ways in which research into invasive species management might be approached. Two broad research approaches can be identified: tactical and strategic approaches. In general terms, tactical research focuses on issues such as the development of appropriate control methods while strategic approaches are concerned with how those methods are deployed over large temporal and spatial timeframes (Moody and Mack 1988, Williams and West 2000, Downey and Sheppard 2006). In this formulation, tactics and strategy are analogous to the military use of the terms. Most research tends to focus on tactical issues because this is the level at which we have the greatest knowledge and certainty and for which our scientific tools are best adapted. However, both approaches are important. Once an invasive has moved well into the spread phase it is only through a combination of effective control methods applied in a strategic manner that will ultimately result in successful control (Moody and Mack 1988).

It is fair to say that most research and management effort relevant to the WTR has focused at the tactical end of the scale and that this is the research area where resources are most easily obtained. Strategic approaches, which are key to the successful deployment of tactical approaches and ultimately to the successful control of spreading invasives, are less well investigated and resourced. This is not to say, however, that strategic approaches to invasives research and management are not understood nor appreciated in the WTR. Indeed, there are a number of examples of clearly considered strategic approaches to weed issues. At the level of planning, the development of risk assessment frameworks (e.g. Harrison and Congdon 2002) and priority lists (Bebawi et al. 2001, Werren 2001) are examples.

An example of a strategic approach employed during on-ground management is the geographic prioritisation used in pond apple control, start-upstream-and-work-down strategy (P. Devine, pers. comm.), which takes into account some, but not all, of the processes underpinning the spread of this weed. With the exception of the risk assessment frameworks mentioned above, however, there are few tools available that assist managers in implementing successful control programs at scales larger than that of individual sites. Such tools require a significant understanding of the ecological and physical processes underpinning spread but also need to be able to incorporate the influence of the interaction between control activities and spread.

The need for utilising both tactical and strategic approaches in meeting the challenge of invasive species, particularly those that have moved beyond the establishment and into the spread phase is highlighted by Bomford's (2003) six criteria for successful eradication. In the Australian context Bomford suggests that six criteria must be met for successful eradication of an invasive species and that failure to meet all six will mean that eradication of a well-established mainland population is unlikely to be successful. These criteria are:

- Rate of pest removal exceeds rate of increase at all population densities.
- Immigration of pests into the control area is zero.
- All pest animals are at risk of control.
- The pest can be detected at low densities.
- Discounted cost: benefit analysis favours eradication over ongoing control.
- The socio-political environment is permissive with respect to the necessary control methods required.

It is clear from these criteria that control needs to incorporate an understanding of population dynamics and spread and be implemented in a manner in which these are managed at a variety of spatial scales. In addition, because control of invasive species can be both an economic and ethically charged issue, and because many invasives achieve a great deal of their spread through human agency, an understanding of the socio-economic context and influence on management approaches needs to be explicitly considered in many cases. Ideally, these socio-economic considerations should be incorporated, through modelling tools, into management planning.

The need to consider such a variety of factors in making management decisions, and the need to do so at a variety of spatial scales, means that if managers are to be successful in meeting the challenge of a single species' invasion, let alone that of a suite of invasions, then they must be skilful in making complex decisions. Not only this, but they must often do so in the face of a dearth of information about the processes driving the invasion and the situation on the ground. This is an unenviable position and one in which research can provide assistance in the form of tools that allow managers to make their decisions in the context of established frameworks that incorporate existing knowledge of the system and processes underlying the issues at hand. Such tools can be simple classifications that allow quick decisions to be made, e.g. species is widespread – control in sensitive sites only, species is localised – eradicate, or they may be complex, e.g. detailed models of invasion processes that predict invasion outcomes and can be based on simple logic through to complex mathematical or statistical models. Such decision support systems (DSS) can be developed and applied for implementation in all stages of the management of biological invasions, from frameworks to assist in identifying the types of species that should be stopped prior to introduction, to determining the appropriate management effort required to achieve a desired level of control. They can also be used to predict the relative 'value' outcomes of different courses of action, and this is one area of research that is being actively pursued outside the Wet Tropics. There would be value in collaborating with researchers on these methods using Wet Tropics case studies. Models also need to be ground-truthed and adjusted to real world conditions. A collaborative project with the Decision Theory CERF hub, using Wet Tropics invasive species, setting priorities through formal decision analysis, modelling likely outcomes of control scenarios, adjusting models in light of on-ground experience and monitoring performance indicators, is something that should be considered. While such tools do not make decisions for managers, they assist managers by identifying likely outcomes of particular actions. In both workshops and discussions with managers during the preparation of this report, the development of DSS for application in the WTR was consistently expressed as a pressing need.

In MTSRF Project 2.6.6 two forms of DSS are being developed. The first is a risk assessment system for identifying potential or new invasives of high impact. The basis of these traits is the utilisation of information on existing invasives to identify those traits and trait combinations that result in high impact. The second form of tool being developed uses ecological data on the processes underpinning dispersal (and therefore invasive spread) to predict the pattern of spread of invasive plants. This tool will allow assessment of the influence of management on the pattern and rate of invasive spread and will thus allow assessment of the relative effectiveness of alternative management actions.

For DSS to work effectively they must reflect the conditions in which they are being applied. Given the uniqueness of WTR ecosystems this means that for many aspects of invasive species control specific DSS tools will need to be developed from scratch or existing DSS tools will need to be significantly modified to adequately reflect the processes underpinning invasion in complex tropical ecosystems. In many instances, however, the basic data required is unavailable for the WTR context. Thus, a clear research need is an improved understanding of invasion processes in tropical systems. It needs also to be remembered that invasions are processes involving people and that an understanding of the social and economic context and processes are also important in the development of DSS tools for some types of invasion or aspects of the management of invasive species.

Thus a major research need is a predictive understanding of invasions in tropical ecosystems as a process:

- Of single species spread through landscapes.
- Of species interactions in complex communities.
- Under human social and economic influence.

Given the taxonomic and functional diversity of current and future invasive threats to the WTR this cannot be done in the context of a single type of invasion but will have to be repeated for the major invasives groups, e.g. woody plants, fish, etc. Such information forms the basis not just of an understanding of invasions but also of DSS that can be utilised in successfully combatting them.

In addition to these more general research needs, Table 17 summarises the research needs for specific species and types of invasives identified in the preceding sections and a summary of research already undertaken appears in Appendix 1, Table 1.

Table 17. This table summarises the major categories of research need for each of the major groups of invasive threat. These needs are identified from all the data and information sources used in the report. Specific research needs for each category of invasive threat are also identified at the end of each category's section. All of the invasive species management responses have the same basic structure in common and so the the research needs will be sorted under these basic headings: 1) prevention of introduction, 2) early detection, 3) prevention of spread, 4) eradication, 5) research, 6) education and awareness. The main objective common to the management of all invasive species issues is to prevent introduction of invasive species in the first place. This means identifying candidate and sleeper species and being prepared for them in case they do arrive, or in case they do become invasive, as well as blocking their entry pathways. (*) = can be applied through all stages of invasion.

Management Action	Research Needs
Prevention of introduction	Refine risk assessments to: identify candidate and sleeper species, identify current and future vectors of spread, e.g. water, migratory birds and bats, humans and vehicles. Undertake functional traits analysis to identify potential for invasiveness or weediness. Develop the capacity to predict risk and prioritise management strategies where uncertainty exists * develop decision support systems and analytical hierarchical decision trees for specific invasive species issues such as: invasiveness, distribution, practicality and cost of control, means of dispersal and threats to WH values *.
Early detection	Use bioclimatic modelling to predict potential range and habitat of invasive species. Examine survey methods to ensure distribution of species data is accurate. Develop effective techniques and protocols to detect small populations of new introductions and recently naturalised species. Evaluate the current and potential geographic distributions and habitat types of potential WTR pests: foxes, deer, common myna, cats, dogs, Undertake benefit-cost analyses to evaluate likely outcomes and the relative worth of action and document costs of invasive species control programs at all stages to enable evaluation of effectiveness *. Develop integrated models of spread and control to enable assessment of management outcomes. Document the distribution of pest fishes. Determine what stream and habitat types various pest fishes are most prevalent in. Confirm the genetic identity and distribution of the hybrid form of *O. mossambicus* and define its ecological tolerance ranges. Develop risk assessment protocols that allow for better prediction of potential likelihood of establishment and impact from potential pest fish species not yet present. Describe WTR invertebrate biodiversity: taxonomy, distribution and community structure, to enable identification and detection of potential invasive pests and to develop management plans. Develop appropriate monitoring methods for detecting and delimiting invertebrate invasions and assessing management success. Evaluate the potential geographic distributions and habitat types of potential WTR pests including tramp ants, exotic earthworms. Improve surveillance and management of tramp ants. Identify pathways of introduction and vectors of dispersal. Map potential distributions and habitats most susceptible to invasion by tramp ants Identify potential environmental diseases and their impacts, possible pathways of introduction and how to detect them.

Management Action	Research Needs
	Develop survey protocols for comparative studies between chytrid-free and chytrid-infected areas. Use molecular phylogenetics to identify and detect *Phytophthora* spp in soil and plant tissue. Identify areas of high conservation value at risk from *P. cinnamomi* and the potential pathways of disease dispersal to these areas.
Prevention of spread	Develop an immunocontraceptive for pigs. Measure the impact of control on pig population dynamics and distribution, to guide the allocation of control effort that can contain or limit populatons in key areas. Collect biological and autecological data of weed species: ecological tolerances dispersal mechanisms seedbank size and longevity time to reproductive maturity population dynamics Evaluate hygiene protocols to see if they are effective in preventing spread of disease. Develop a hierarchy of risk using the conservation status of species at sites and the status of disease at sites and use this to minimise spread and potential impacts of disease. Work with industry (tropical fruits, vegetable, nursery industry) at local, state and national level to determine the critical control points where frogs enter products and where they can be most effectively removed. Investigate how *B. dendrobatidis* is dispersed between water bodies.
Eradication	Find suitable biocontrol agents for large established weed infestations. Develop integrated pest management programs for weeds. Develop management and control strategies for selected weed species, focusing on new incursions. Develop short-term control methods for detecting and capturing pest fishes and methods for removing small populations. Develop technologies for long-term population control of pest fish. Develop species-specific control methodologies. Develop methodologies for delimitation of infestations. Evaluate habitat manipulation to improve environmental suitability or general well-being of susceptible organisms, plants etc.
Research	Quantify the actual and ongoing ecological impacts of key invasives in the WTR - are they still causing declines or have native communities accommodated them? Describe the interactions between invasive carnivores, currently dingoes, dogs, and cats, and the potential consequences for prey populations of changes to these interactions wrought through control. Study the interactions between predation by wild dogs, cats, foxes and the conservation status of key species. Study the interactions between the distribution and abundance of wild dogs, feral cats, foxes and native predators such as quolls, snakes, goanna. Investigate the status of populations of affected species in WTR areas that have had cane toads for a long period. Priority groups would be predators including vertebrates such as goannas, frog-eating snakes, quolls and other anurans and invertebrates and communities upon which cane toads predate, e.g. arthropod communities.

Management Action	Research Needs
	Quantify the impact of feral pigs on specific rare and endangered plant species in the WTR, e.g. wild banana *Musa* spp. Develop further impact assessment methods for feral pigs: environmental, economic and social costs. Develop an integrated approach to feral pig management incorporating an understanding of the interaction between their spatial distribution and control activities, and control effort and socio-economic and institutional arrangements. Study population dynamics and individual movements of feral pigs in the WTR. Investigate the possibility that cane toads are having a negative impact upon other native, ground-dwelling vertebrate fauna (besides rainbow bee-eaters), via their role as opportunistic predators. Study the interactions and impacts of invasive plants on native biota. Collect biological and autecological data of selected weed species, focusing on new incursions. Study the relationships between weed functional groups and associated disturbance regimes. Study the impacts of climate change: dynamics between native and introduced species. niche displacement. changes in community structure and disturbance regimes that influence the invasive species' ability to establish and spread. Undertake genetic studies to determine: origin (important in search for biocontrol agents) time of introduction (single or multi) patterns of introduction and dispersal. Identify factors that facilitate weed invasions in WTR rainforests. Describe dispersal mechanisms and spread of invasive plant species in rainforests. Determine impacts of tilapia on native aquatic fauna and ecosystems. Measure the economic costs of pest fish to determine the true impact of pest fishes. Describe the social context of fish invasions, including impacts of recreational fishing, ecotourism, peoples' perceptions of the values of wetlands, impacts on indigenous values. Identify and quantify the impacts of environmental invertebrate pests in the WTR. Increase taxonomic knowledge of native earthworms in the WTR. Determine how native earthworms interact with exotic earthworms in a range of contexts, from undisturbed to highly disturbed landscapes. Investigate the role of different functional types of earthworms (e.g. surface-living compared to burrowing earthworms), in terms of soil physical and biogeochemical properties and overall ecosystem species composition. Quantify the effects of introduced honeybees on native flora and flower-visiting fauna, with special consideration of spatial and temporal scale. Determine the key factors for establishment, patterns of dispersal and reproductive requirements of priority tramp ants. Quantify the direct and indirect impacts and mechanisms of these impacts, of tramp ants on biodiversity and other environmental and socio-economic values. Review known impacts of tramp ants, especially those species that are potential threats to the WTR. Use genetic diversity studies to determine the historical spread of *P. cinnamomi* in the WTR to place it in context with species from other

Management Action	Research Needs
	places within Australia and overseas. Investigate the separate effects of temperature and altitude on (or identify other environmental factors that influence) mortality and infection rate from *B. dendrobatidis* in WTR amphibians. Determine impacts of chytridiomycosis in frogs in other WTR ecosystems besides rainforest. Determine what physiological factors enable species populations to survive infection and what factors make others susceptible to infection. Increase understanding of epidemiology of ranaviruses in wild amphibians in the WTR and the potential for imported fish and reptiles to bring the disease here. Determine what environmental factors influence the pathological outcomes of disease.
Education and awareness	Provide frameworks for assessing and identifying garden species that are not to be imported, sold or grown in the WTR. Determine the role of community in weed introductions and dispersal, weed prevention and control. Encourage and maintain community involvement to improve surveillance and detection of invasive species introductions. Assess the effectiveness of public education programs in getting their message across.

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Appendix 1

Table 1. Summary of research projects that have been undertaken or are underway. Note, this is not an exhaustive list by any means.

Pest spp	Project
Feral pig (*Sus scrofa*)	
- Development of monitoring systems for feral pigs to assess population levels, e.g. remote cameras (BRS, NFACP). - Quantification of environmental impacts of pigs on seedling survival: spatially and temporally (Mitchell et al., submitted). - Prediction of natural boundaries for feral pig populations to establish improved management units (DNRMW). - Investigation of the pig diet and trapping strategies in rainforests of the WTWHA (Mitchell and Dorney, RF CRC). - Evaluation of the effectiveness of cage trap doors and triggering mechanisms; investigation of animal recognition systems (DNRMW). - Economic evaluation of feral pig control strategies and pig impact to the banana, sugarcane and tropical fruits industries in WT (Mitchell and Dorney 2002). - Development of a preliminary model of feral pig management within WTR based on ecological and management data available (BRS NFACP). - Performance indicators of trapping and hunting as control methods (Vernes & Johnson 1999, Mitchell and Dorney 2002). - Best practice feral pig management Burdekin River Catchment (DNRMW). - Development of effective poison for feral pig baits (BRS NFACP). - Development of a target-specific bait (e.g. PIGOUT® (IA CRC, BRS). - Evaluation of attractants and additives for improved bait delivery systems for alternative feral pig control toxins, self-watering toxin delivery systems (DNRMW). - Investigatation of tissue residue and degradation of 1080 bait in poisoned feral pigs (DNRMW). - Investigation of options for managing feral pigs (Pest Animal CRC). - Determine the level of feral pig control required to minimise threats to native spp and ecological communities (Arthur Rylah Institute for Environmental Research, ARIER). - Review of existing Feral Pig control in Australia and identify information gaps (ARIER). - Feral pigs in Qld (McGaw & Mitchell 1998).	
Cane toad (*Bufo marinus*)	
- Development of a cane toad-specific toxin (IA CRC, UQ) - chemical (venom and toxins for toad-specific poisons) and microbial ecology (pheremones to attract females to traps, biocontrol agents). - *Bufo marinus*: biological control (CSIRO Entomology, CSE), other control techniques (Uni. of Sydney, JCU, Charles Darwin Uni.) - Size and diet of cane toads in rainforest of northeast Qld (Werren and Trenerry 1984).	

Pest spp	Project
- Cane toads as potentially significant vectors of salmonella (O'Shea et al. 1990). - Population biology of cane toads in northern Australia (Alford et al. 1995) - Parasites of cane toads (Delvinquier and Freeland 1988). - Competition between cane toad and native anuran larvae, Darling Downs, southern Qld (Williamson 1999). - Effects of adult sex ratio on female breeding success and environmental manipulation of toad spawning ponds (Uni of Sydney). - Predation on the cane toad by the black kite (Mitchell et al. 1995). - Spawning site selection by cane toads at an invasion front in tropical Australia (Hagman & Shine 2006). - Assessing the potential impact of cane toads on Australian snakes (Phillips et al. 2003). - Palatability of cane toad tadpoles to a predatory fish decreases with development (Lawler & Hero 1997)	
Feral cats and stray domestic cats (*Felis catus*)	
- Review of methods to determine the abundance of feral cats (ARIER). - Increase understanding of interactions between cats and native wildlife and other predators (ARIER). - Review of existing feral cat control in Australia – identification of information gaps (ARIER). - Review of Threat Abatement Plans (TAP) for feral cats. - Development of a cat-specific toxin (Vic Institute of Animal Science). - Population and community-level impacts of feral cats on native fauna - several studies indicate direct predation is the most important process involved (Dickman 1996).	
Dingo (*Canis familiaris (dingo)*), owned and wandering dogs	
- Ecology of livestock predation (NFACP, BRS). - Evaluation and development of best practice wild dog management (NFACP, BRS). - Wild dog management: satellite collars for tracking movement, evaluation of strategic wild dog control in Qld (USQ, UQ, QPWS, DNRMW). - Fraser Island dingo management: dingo diet, prey, genetic structure and spatial and temporal variation in dingo activity (UQ, QPWS). - Best practice baiting: evaluation of large-scale, community-based 1080 baiting campaigns, time to recolonise after baiting, source of recolonising dogs, most effective way to deliver bait (NFACP, BRS, Barcaldine, Blackall and Tambo shires). - Refinement of the 1080 bait degradation model (DNRMW). - Preparation of cyanide ejector registration package (DNRMW). - Impacts of canid-baiting on quolls (BRS).	
Rabbits (*Oryctolagus cuniculus*)	
- Strategic management of RCD (NFACP).	

Pest spp	Project
	- Adaptive rabbit management in agricultural areas (Rural Lands Protection, Stanbroke Pastoral Co, DNRMW). - Crop and pasture protection from rabbits in native bush remnants. - Review of existing rabbit control in Australia – identification of information gaps (ARIER). - Review of TAPs for feral rabbits. - Reduction of impacts using ecological methods, RCD and myxomatosis (Vertebrate Pest CRC, CSIRO Sustainable Ecosystems (CSE). - Methods to reduce spread.
Fox (*Vulpes vulpes*)	- Review of TAPs for European red fox (BRS, NFACP, ARIER). - Assessment of the effectiveness of habitat manipulation as a fox control strategy. - Increased understanding of feral rabbit and feral fox control required to minimise threats to native spp and ecological communities. - Review of existing red fox control in Australia – identify information gaps (ARIER). - Increase understanding of interactions between foxes and rabbits. - Development of an immunocontraceptive vaccine for fox control (Vertebrate Pest CRC, CSE).
Rusa (*Cervus timorensis*), Chital (*Axis axis*), Fallow (*Dama dama*) deer	- Review of impacts, survey and control methods of wild deer (NFACP). - Deer in Qld. Pest status review (Jesser 2005), deer in the WTR (Hudson, in prep.).
Common myna (*Acridotheres tristis*)	- Control of common mynas and other invasive pest birds (ANU), ARF, CCC). - Investigation of common myna impact on native birds: loss of nesting hollows, eggs and chicks.
Pest populations	- Modelling of pest populations and various scenarios, e.g. climate change using STELLA (Scanlan, DNRMW). - Interactions between feral cats, foxes, native carnivores and rabbits in Australia (Robley et al. 2004).
Aquatic vertebrates	- Genetic testing of feral populations of tilapia (Mather and Arlingon 1991). - Effects of native and exotic fish introductions and translocations (Burrows 2002, Webb 2006). - Determination of the thermal tolerances most favoured by tilapia *O. mossambicus,* then development of a spatial model to predict their potential geographic distribution (Schnell et al. Uni of Sydney honours project 2006).

Pest spp	Project
- Ecological niche modelling of carp and tilapia in the Americas to predict geographic potential of both species. (Zambrano et al. 2006). - Diet of the exotic Mosquitofish, *Gambusia holbrooki*, in an Australian lake and potential for competition with indigenous fish species (Arthington & Marshall 1999). - Threats to freshwater fishes of the WTR (Pusey et al., unpubl.) - Translocation of recreationally desirable fish is detrimental to the maintenance of local biodiversity (Pusey et al. 2003). - Tilapia environmental and life history vulnerabilities for management (Invasive Animals CRC, FNQ NRM, NIWA). - Distribution of exotic and translocated native fish species in NQ. - Genetics, ecology and impact of tilapia. - Community and rapid response plans for control of tilapia. - Trials of short term control methods such as manual catch and habitat restoration. - Effectiveness of habitat restoration and how habitat condition affects invasion and dominance of pest fish, based on preliminary studies of *Gambusia holbrooki* . - Ongoing state-wide public education program (DPIF). - Surveillance detection program in Gulf rivers (DPIF). - Long term control measures and life cycle vulnerabilities (DPIF). - Modelling of different management scenarios (DPIF). - Risk assessment screening for potentially invasive freshwater fishes within the WTR (Webb 2006, ACTFR). - Control trials in small bodies of standing water [quarries, ponds] using rotenone techniques (DPIF). - Risk assessment of imported aquatic invertebrates through live aquarium ornamental trade in Taiwan, based on similarity of native geographic regions and invasion record, (Lin et al. 2006). - Impacts of introduced aquarium fish species that have established wild populations in Australia. 'Daughterless carp' genetic technique aimed at long term sustainable control of carp, developed by CSIRO. Works by production of male offspring only, reducing population in ecosystem over the long term.	
Weeds	
- Weed Wipeout interactive computer game about weed management, suited for school students (Greig et al. 2006). - Survey of public awareness of weed issues and impacts (Weeds CRC, Martin 2006). - National Weed Detection Project, collaboration between state government agencies, NRM regional bodies, community groups and individuals in two regions in Qld (Morton 2006). - Use of invasive history of weeds in Tahiti and Hawaii to detect candidate species in tropical Australia (Csurhes 1997). - Identification of high priority weeds in wet and dry tropics based on social, cultural, economic and environmental impacts (Bebawi et al. 2001). - Environmental Weed Risk Assessment for the WTWHA based on biological and ecological criteria (Werren 2001).	

Pest spp	Project
- National weed RA (Weber and Panetta 2006). - Planning a national delimiting survey of Siam weed (Maher et al. 2006) - Potential use of spectral signatures to discriminate individual weed species (Harriss and Gillieson 2006). - Use of Landsat images to map distributional change of *A. nilotica* on Mitchell grass plains, Qld to determine level of threat at property level (Lawes and Wallace 2006). - Evaluate use of indirect remote sensing (RS) and GIS to map and model distribution of *C. odorata* in Nepal (Joshi et al. 2006). - Use of hyperspectral RS to detect and map invasive plant species (e.g. lianas) in a tropical dry forest (Castro-Esau 2006). - Use of remote sensing for detecting pond apple infestations (Phinn et al. 2002) - Use of Landsat TM images for mapping lantana distribution. - Integrated weed management guidelines (NSW DPI). - Coordination of salvinia, alligator weed and cabomba national strategies (NSW DPI, DNRMW). - Water weed management and WoNS class 1 plant pests (DNRMW). - WT weeds project - herbicide/chemical trials (DNRMW). - *Cabomba* spp biocontrol native range (Sth America) and plant ecology studies (DEH, CSIRO Ento). - National assessment and best practice management for *Cabomba* (DNRMW). - *Hymenachne amplexicaulis* best practice manual (DNRMW), WoNS coordination (DNRMW). - Evaluation of risk of off-target damage through application of chemicals to control hymenachne(DNRMW). - Weed eradication feasibility and program evaluation (DNRMW, CRC AWM). - Hymenachne management in the Daintree River system (Douglas SC). - Ecological basis for integrated management of Hymenachne (DAg, Defeating the Weed Menace). - National Hymenachne education and awareness program. - *Chromolaena odorata* biocontrol in PNG: release of gall fly and a moth and leaf-mining fly (ACIAR), chemical trials (DNRMW). - Navua sedge (*Cyperus aromaticus*) chemical trials (DNRMW). - Establishment of a regional salvinia weevil breeding and distribution facility in NQ (Defeating the Weed Menace). - Replacement of exotic weeds with native plants that have same fruit traits so that frugivores are not disadvantaged in habitat restoration and frugivore dispersal of weed (Gosper and Vivian-Smith 2006a-c, Gosper et al. 2005). - Ecology and management of bird-dispersed weeds (Vivian-Smith et al. 2007). - Manipulation of fruit dispersal by changing abundance and quality of seed/fruit dispersed (CRC AWM,Vivian-Smith 2006, Lawrie 2002, Buckley et al. 2006). - Traits and functional groups of invasive plant spp in tropical rainforests (Murphy et al. 2006, Buckley et al. 2006).	

Pest spp	Project
- Weed functional groups (CRC AWM). - Vertebrate dispersal of plants in tropical rainforest (Westcott and Dennis 2006, Metcalfe et al. 2006). - Tracking weed distribution post-Tropical Cyclone Larry to develop better predictive models for weed control purposes (CSIRO Sustainable Ecosystems). - Measurement of seed dispersal and seedling distribution in a landscape context in the Tully region (CSIRO Sustainable Ecosystems). - Evaluation of commercial potential and ecological appeal of acacias in Malaysian (Krishnapillay et al. 2005). - Chemical trials and integrated control and best management practices on *Lantana camara, L. montevidensis, Praxelis clematidea*; lantana containment zones, strategically managing lantana for biodiversity conservation, introduction/use of lantana bug as a biocontrol agent (NSW Lantana Taskforce, CRC AWM, DPIF). - Integrated weed management of *Mimosa pigra* (Paynter 2003) - *Alternanthera philoxeroides* (Uni W. Syd), biological control (CSIRO Ento). - *Annona glabra* Biological and ecological research, National Pond Apple education and awareness (DNRMW). - WoNS coordination (DNRMW). - Pond Apple seed longevity (Setter et al. 2004). - Herbicide impact on Siam weed (Setter & Campbell 2002). - Plant traits predict impact of invading species (Australian sub tropics) McIntyre et al. 2005). - Catchment approach to weed control involving landholders, shire council, and community-based committee, Trop Weeds Research Centre, CSIRO, DNRMW and RITE, WoNS, QDPIF (Landsberg et al. 2006). - Integrated weed management (Buckley et al. 2004, Paynter and Finnigan 2004). - Ecology of WT weeds (Setter & Setter 2003,RF CRC, CRC AWM, WoNS, 4TWP, DNRMW). - Evaluation of weed eradication programs (Panetta 2005, 2007, Panetta & Timmins 2004). - A new role for weeds in rainforest restoration (Neilan et al. 2005). - A model for community-based weed detection network for use in Australia (Morton 2006). - Invasion of tropical freshwaters by alien aquatic plants (Mitchell & Gopal 1991). - Acanthaceae species as invasive alien plants on tropical Indo-Pacific Islands (Meyer & Lavergne (2004).	
Invertebrate pests	
- Services and disservices by rainforest insects to the horticultural crops in the WTR (Blanche et al. 2002). - TAP to reduce impact of six tramp ants on Aust biodiversity (Monash Uni 2006). - Disruption of bird-plant pollinations systems in southern Australia (Paton 2000). - Potential suitability of NQ rainforest sites as habitat for the Asian papaya fruit fly (Hadwen et al. 1998) - Giant African snail (Watson 1985).	

Pest spp	Project
- Exotic earthworms (Baker 2006).	
Disease	
- Phytophthora cinnamomi in the WT: assessment and mapping (Brown 1976, 1999, Gadek 1999, Gadek and Worboys 2003, Pryce et al. 2002) recovery from infection (Worboys 2006, Metcalfe and Bradford unpubl.) - Review of TAP for *P. cinnamomi* 2006 (MurdockLink). - Phytophthora in natural vegetation in Qld (Pratt et al. 1972) - A review of declining frogs in north Qld (McDonald & Alford 1999) - Declines in populations of Australia's endemic tropical rainforest frogs (Richards et al. 1993, Trenerry et al. 1994). - West Nile Virus and Wildlife (Marra et al. 2004). - Epidemic disease and decline of Australian rainforest frogs (Laurance et al. 1996). - Defining plant resistance against P. cinnamomi, application of resistance to revegetation (Deakin Uni). - Induced resistance in native vegetation of P. cinnamomi and innovative methods to contain and/or eradicate within localised incursions in areas of high biodiversity in Australia (MurdockLink). - Avian malaria, climate change and native birds of Hawaii (LaPointe et al. 2005) - Review of management of sites that could be or are threatened by *P. cinnamomi* (MurdockLink). - *B.dendrobatidis* in the WT: recovery or resistance to infection (McDonald et al. 2005, JCU). - Map the distribution, review TAP, increase understanding of epidemiology, transmission and dispersal of amphibian chytrid fungus in Australian ecosystems (JCU).	
Other	
- How biology and economics can be used together to determine policy by using optimal control methodology (examine costs of certain management stategies vs effort to determine what is most cost-effective (Brooks et al. 2006). - Population biology of invasive species (Sakai et al. 2001).	