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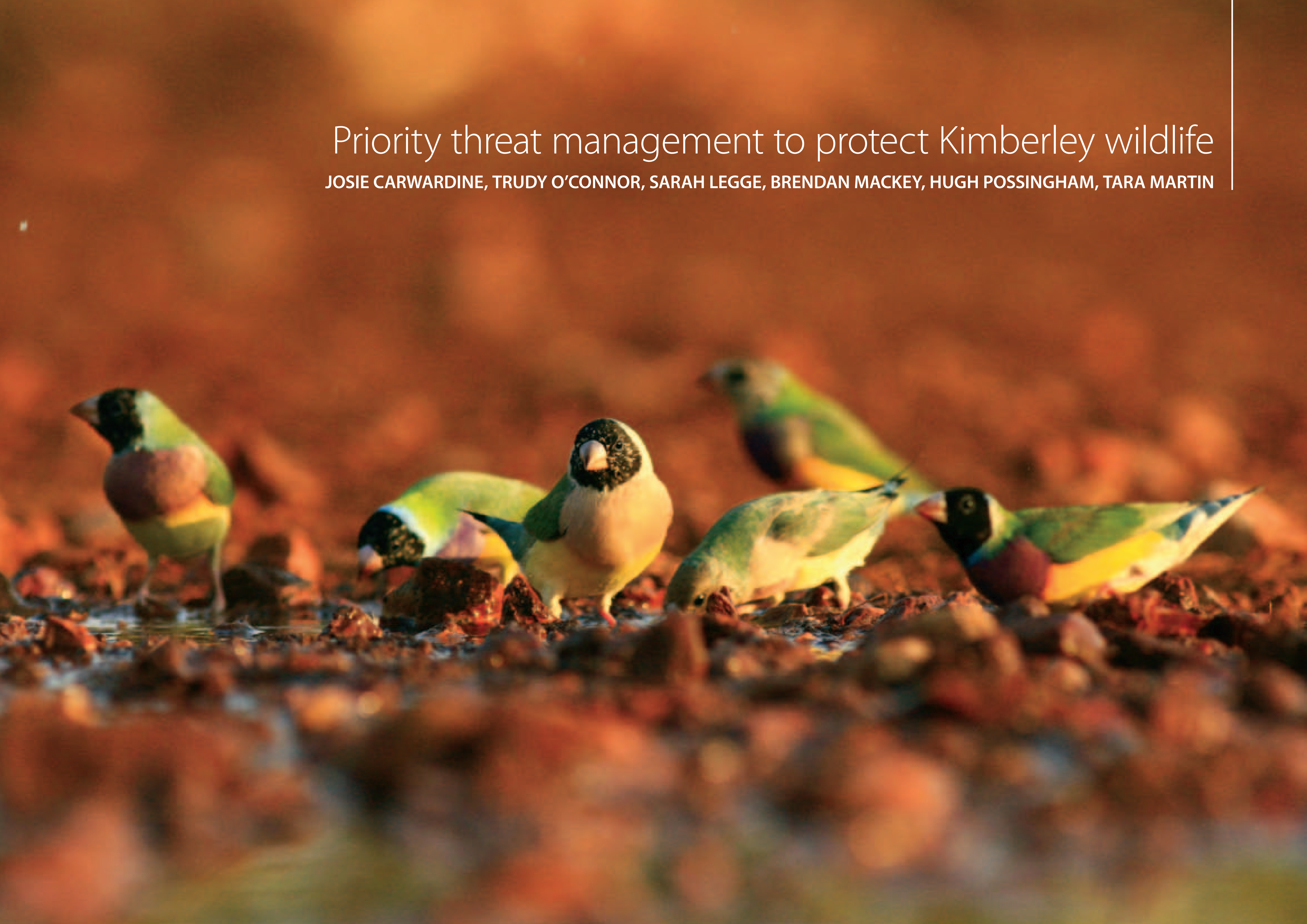

Priority threat management to protect Kimberley wildlife

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This report details the science on prioritising threat management for Kimberley wildlife. CSIRO Ecosystem Sciences was commissioned by The Wilderness Society on behalf of the WildCountry Science Council to carry out this research. The WildCountry Science Council, a group of Australian and international ecological scientists, provides independent advice to The Wilderness Society. CSIRO worked in collaboration with the co-authors listed on this report and with the assistance of many others who have generously shared their time, knowledge and expertise to provide data and comment on the report. The report has been formally peer-reviewed both internally and externally to CSIRO.

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Gouldian Finches
Erythrura gouldiae.
PHOTO: BRUCE DORAN

FACING PAGE BACKGROUND
Pied Butcherbird
Cracticus nigrogularis.
PHOTO: GLENN WALKER

INSETS
Northern Cave Bats
Vespadelus caurinus.
PHOTO: GLENN WALKER

Northern Spiny-tailed Gecko
Strophurus ciliaris.
PHOTO: RAY LLOYD/ AUSTRALIAN WILDLIFE CONSERVANCY

Double-barred Finch
Taeniopygia bichenovii.
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Echidna
Tachyglossus aculeatus.
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Sacred Kingfisher
Todiramphus sanctus.
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Northern Quoll
Dasyurus hallucatus.
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LOCHMAN TRANSPARENCIES

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Rainfall in the Kimberley is highly seasonal, with the wet season replenishing watercourses and causing floods that are important for the life cycles of some species. Bell Creek, King Leopold Ranges Conservation Park.
PHOTO: GLENN WALKER

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PHOTO: PAUL DOUGHTY

EXECUTIVE SUMMARY

This project is led by scientists in conservation decision appraisal and brings together a group of expert ecologists and land managers working in the Kimberley region. We provide a prioritisation of threat management in the region based on cost-effectiveness for wildlife, which is the likely benefits to wildlife divided by cost. We identify the key threat management actions required to restore and maintain functioning populations of wildlife in the Kimberley region, the level of investment required and the likely improvement in wildlife persistence gained per dollar spent on each action. Our focus is on actions that are technically and socially feasible and which abate specific mainland-based threats to wildlife, defined here as native vertebrate fauna (additional threats on the islands off the Kimberley coast were not addressed).

The impending risk of species extinctions in the Kimberley means that this exercise was carried out rapidly and under significant resource and information constraints. Scientific data on species distributions and the impacts of threatening processes are limited; hence our approach relies heavily on the knowledge of experts. We could not consider all facets of biodiversity and we focused on the main existing threats. We do not address the effectiveness of current conservation efforts, nor address the large-scale cooperation required for implementation. Our approach applies focuses on the persistence of wildlife using a scientific approach, but we acknowledge that other social, economic and cultural perspectives are required for a comprehensive conservation management plan. Such information can be incorporated into our framework and may affect the relative priority and suitability of different actions.

Information was collected at two expert workshops with many follow-up consultations. Experts identified key broadscale threat management actions for improving wildlife persistence:

1. combined management of fire and introduced herbivores
2. eradication, control and quarantine of weeds
3. control of introduced predators, particularly feral cats.

For each action, in each of the Kimberley's five bioregions, they estimated costs over a 20 year period, feasibility of implementation (from 0–100%) over various land tenures and the probabilities of functional persistence in the landscape over 20 years (hereafter probability of persistence) of Kimberley wildlife species with and without the action taking place.

We used this information to estimate, over 20 years: the likely functional losses of wildlife species (where likely lost species = probability of persistence less than 50%) if these actions are not carried out; the financial costs and actions required to create a high probability of functionally securing all wildlife species (where likely secured species = probability of persistence of at least 90%); and the cost-effectiveness of each action in each bioregion, i.e. the likely improvements in wildlife persistence per dollar spent.

The charismatic Gouldian Finch *Erythrura gouldiae* is one species that has maintained a relative stronghold in the Kimberley, while declining more severely elsewhere in northern Australia.
PHOTO: STEVE MURPHY/ AUSTRALIAN WILDLIFE CONSERVANCY

In summary, our scientific findings are:

- **Without effective investment in the management actions we identify, 45 species of wildlife are likely to be functionally lost from the Kimberley in the next 20 years.** This includes mammal species endemic to the region such as Scaly-tailed Possum (Wyulda) and Monjon Rock Wallaby, as well as threatened species that have already disappeared from other parts of northern Australia and for which the Kimberley is their last refuge (e.g. Golden-backed Tree-Rat and Golden Bandicoot). Without effective management many other species would be at risk of declines, including seed-eating birds such as the Gouldian Finch, carnivorous reptiles such as the Spotted Tree Monitor and small mammals such as the Western Chestnut Mouse.
- **The wildlife of the Kimberley is likely to be secured with an initial and immediate investment of $95 million, followed by an ongoing investment of $40 million per annum,** directed towards the key management actions and safeguarding populations of highly sensitive species in cat-free sanctuaries (some eight species with lower persistence probabilities across landscapes will need protection on islands and fenced areas on the mainland). Assuming this is spent effectively, this equates to less than $1 million annually per species saved from likely loss and creates a high likelihood of securing Kimberley wildlife species. Activities that enable conservation management, such as planning across social groups, large scale cooperation and establishing conservation areas, would cost additional funds.
- **Current annual investments in conservation management would need to be at least doubled, and spent optimally and effectively, to secure the Kimberley's wildlife species.** A sum of approximately $20 million per year is currently spent on conservation management by a variety of existing organisations working in the Kimberley and its islands. According to our analysis, even if this amount were spent optimally and effectively on the mainland-based actions we recommend, it would be insufficient to avoid the likely functional loss of 31 wildlife species from the region.
- **Actions vary in terms of their cost-effectiveness.** The single most cost-effective management action would be to reduce the impacts from feral cats (at $500,000 per bioregion per year) with a combination of education, research and the cessation of dingo baiting, however feasibility of success is low. The next most cost-effective action is to manage fire and introduced herbivores (at $2–7 million per bioregion per year); this action is highly

The Western Chestnut Mouse *Pseudomys nanus* is one of the species predicted to be lost from at least one of the Kimberley's bioregions without effective conservation management. PHOTO: JOANNE HEATHCOTE/ AUSTRALIAN WILDLIFE CONSERVANCY feasible and, if implemented effectively, would generate large improvements in probabilities of persistence for almost all wildlife species.

- **Investment in the actions we identify has vast potential to provide benefits outside wildlife conservation,** such as improved persistence of plants and invertebrates, carbon benefits, conservation of Indigenous knowledge, enhanced livelihoods for people in the region, soil and water conservation. It is important that implementation of conservation actions is strategically targeted to maximise these and other benefits.

A lack of available data gave rise to a number of analytical limitations:

- our estimates of wildlife persistence, costs, feasibility and other benefits are largely the professional judgments of experts with extensive experience in the region rather than being derived from formal ecological data from field surveys
- our priorities for wildlife do not necessarily reflect the needs of other taxa, such as plants and invertebrates, ecological and evolutionary processes and adjacent marine environments
- our predictions of wildlife persistence should be considered 'best case' scenarios as we did not address potentially emerging threats such as climate change.

Many important factors of conservation management planning in the region were outside the scope of this study. Further efforts are required to support discussions, careful and local negotiations and planning with Kimberley residents and land-users, particularly Traditional Owners, pastoralists and the tourism industry. Successful implementation will require an appropriate alignment of conservation goals and other aspirations and priorities of the Kimberley community. Terrestrial wildlife conservation priorities should be integrated with existing initiatives that focus on the perspectives of these groups, as well as those that address the conservation of other biodiversity assets, such as vegetation communities and the marine environment. Efforts are also required to coordinate existing conservation initiatives and to establish longer-term commitment to continued funding for those that are cost-effective. Several activities may assist the successful implementation of wildlife conservation actions, including support of the Indigenous Protected Areas program, negotiating stewardship programs and other incentive schemes with pastoralists, and policy reform, many of which are already under negotiation or underway.

This research provides a new insight into the actions and costs required to avoid wildlife losses in an iconic region of Australia. We hope that the information provided here will be useful for:

- understanding the likely Kimberley wildlife declines under different investment scenarios
- prioritising funds for conservation management in the Kimberley
- grounding conservation investment in the region in a defensible and rigorous cost-effectiveness framework, which can be adapted and built upon to consider broader information and perspectives.

Active management of fire together with control of introduced herbivores is predicted to have substantial wildlife conservation benefits, as well as providing other benefits such as employment.
PHOTO: RICHARD KINGSWOOD/ AUSTRALIAN WILDLIFE CONSERVANCY

Purple-crowned Fairy-wrens *Malurus coronatus* depend on high quality riparian vegetation. This can be damaged by grazing, fire and weed invasion. PHOTO: STEVE MURPHY/ AUSTRALIAN WILDLIFE CONSERVANCY

THE KIMBERLEY – VALUES, THREATS & CONSERVATION

The Kimberley is an iconic region in northern Australia, boasting spectacular and varied landscapes that are home to diverse and unique assemblages of plants and animals. The region covers an area of 30 million ha in Western Australia[1], comprising five Interim Biogeographic Regionalisation of Australia (IBRA) bioregions: North Kimberley, Central Kimberley, Dampierland, Victoria Bonaparte and Ord Victoria Plain (*Figure 1*) (Commonwealth of Australia 2000–2004). Indigenous Australians have inhabited the Kimberley for tens of thousands of years and it remains an important region for contemporary Aboriginal culture. European exploration in 1879 led to pastoral development and grazing has become the predominant use of land in the region. The Kimberley is famous for the thriving pearl industries of Broome, the distinctive pink diamonds of Kununurra and its growing popularity as a tourist destination.

The Kimberley is also known as one of the most ecologically important regions in Australia. It has some 65 species of endemic wildlife: native vertebrate fauna found nowhere else in the world (McKenzie 1991b; Department of Environment and Conservation 2009). The region's remoteness means its ecosystems and species assemblages are relatively intact compared with the rest of Australia. The North Kimberley bioregion is one of only two in Australia (the other being in the Tiwi Islands) likely to retain all mammal fauna for the last 200 years (Burbidge *et al.* 2008). However, the wildlife of the Kimberley is faced with increasing threats. Recent monitoring data has shown alarming declines amongst this globally important suite of native animals (Start *et al.* 2007; Burbidge *et al.* 2008).

Next we give a brief overview of the evolution of the Kimberley landscapes and its biodiversity, the threats faced by wildlife and the current conservation efforts in the region. Following this we provide a rationale for our project on prioritising increased conservation management efforts to protect the wildlife of the Kimberley.

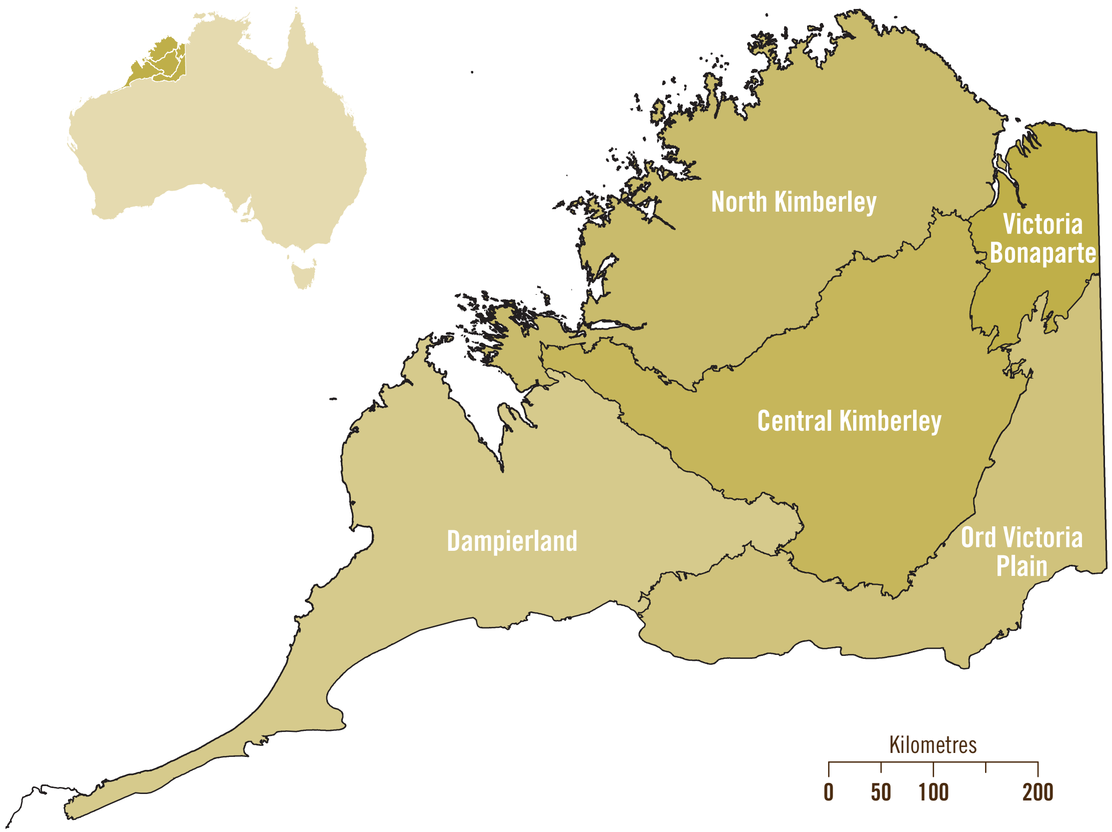


FIGURE 1
The delineation of the Kimberley defined by its five bioregions in Western Australia.
(COMMONWEALTH OF AUSTRALIA 2000–2004)

1 Some ecological definitions of the Kimberley include the entire extent of Victoria Bonaparte and Ord Victoria Plain into the Northern Territory, but we have focused on the Western Australian section for reasons of logistics, funding sources and data consistency.

Evolution and biological values

The landscapes of the Kimberley are ancient and have been evolving for over 1.5 billion years (Gunn and Meixner 1988). The region contains unrivalled examples of the Earth's evolutionary history and past biological diversity. The extensive Devonian limestone reefs there hold rare evidence of the evolution of fish and their transition from sea to land. The flora and fauna of the Kimberley today reflect northern Australia's historical connections to Indonesia in the west and New Guinea in the north (McGuigan *et al.* 2000). The region contains critical ecological and evolutionary refugia of global importance for many resident and migratory species, including three internationally recognised Ramsar wetlands (The Convention on Wetlands 1971), and vast numbers of mound springs, escarpments and caves known to be hotspots for generating and maintaining biological diversity (Morton *et al.* 1995).

Although much of the Kimberley biota is shared with Arnhem Land and Cape York, the Kimberley supports some 65 endemic wildlife species, including the Scaly-tailed Possum *Wyulda squamicaudata*, the Black Grasswren *Amytornis housei* and the dragon species *Diphoriphora convergens* and *Diphoriphora superba*. It also contains high numbers of endemic freshwater fish (Morgan *et al.* 2005) and the highest number of many groups of endemic invertebrates such as land snails (Solem and McKenzie 1991). So far, 309 endemic plant taxa have been recorded in the Kimberley (Paczkowska and Chapman 2000). The true biological diversity and endemicity of the region is likely to be greatly underestimated, because it remains largely unsurveyed by biologists (Department of Environment and Conservation 2009).

This incredible résumé of biological diversity is echoed by the complex landscapes and ecosystems

TOP
Butler's Grunter *Syncomistes butleri* is a herbivorous freshwater fish that prefers deep rocky pools. It is found in the Drysdale and Ord River systems as well as in the Northern Territory.
PHOTO: MARK KENNARD

BOTTOM
Seven-spot Archer-fish *Taxotes chatareus* is an omnivorous fish with a wide distribution, living in fresh and brackish water, particularly estuaries and mangroves.
PHOTO: MARK KENNARD

that can be seen in the Kimberley today. The savanna matrix is dominated by an overstorey of eucalypts with a rich variety of understoreys and is the core habitat for most species. The savanna is naturally fragmented to encapsulate and nurture more discontinuous habitats such as rainforests, rivers and wetlands. Patches of rainforest occur in the high rainfall regions of the north-west and are thought to provide Australia's last undisturbed refuges for many tropical coastal mammal, bird and reptile species (Start *et al.* 2007). Creeks and rivers form numerous independent drainage systems and a diversity of microhabitats such as mound springs are nestled within the rugged, rocky, escarpment country. The Kimberley coastline comprises mangroves, thickets and dune habitats, linking the savanna matrix to a global marine biodiversity hotspot and some of the most magnificent marine tidal cliffs in the world. Further offshore, the Kimberley islands exhibit some of the most pristine samples of biodiversity in Australia.

Natural integrity and threats

Northern Australia has been lauded as being relatively intact in comparison with other parts of Australia and tropical savannas across the world (Woinarski *et al.* 2007). However, in recent years, ecologists have become increasingly alarmed at rapid declines of wildlife species, particularly of mammals and granivorous birds, across northern Australia. There are strong indications that current declines indicate an imminent extinction wave, similar to that which affected mammals of arid Australia in the 20th Century (Franklin 1999; Woinarski *et al.* 2001; Woinarski *et al.* 2010; Woinarski *et al.* 2011). The Kimberley is thus far less affected by these declines, but its ecological integrity varies markedly (Start *et al.* 2007; Vernes 2007). While the relatively intact northern Kimberley has experienced some declines, there are many more reported declines and local extinctions of species in the southern and eastern Kimberley, for example the Boodie *Bettongia lesueur*, once considered common, has long disappeared from the region (Burbidge *et al.* 2008). The offshore islands of the Kimberley region remain relatively insulated from some of the main threatening processes on the mainland and so retain critically important populations of wildlife species lost elsewhere (Conservation Commission of Western Australia 2010).

The biodiversity of the Kimberley is threatened by a range of localised and more pervasive processes, some current and some likely to increase in the near future. Currently, the most serious of these include inappropriate fire regimes, the impacts of introduced domestic and 'feral' herbivores, predation by feral cats, impacts of weeds, pigs and cane toads. Some proposed activities such as mining, tourism and agricultural expansion may exacerbate existing damage and, in particular, affect hydrological regimes. The full consequences of some of these activities are thus far poorly understood. Many of the existing and potential threats are associated with socio-economic activities and processes that have important financial benefits and cultural values for Australia and members of the Kimberley community. Comprehensive land use planning conducted with the community will be important in understanding the full range of trade-offs and opportunities that exist for achieving good social and conservation outcomes. Next we summarise the threatening and potentially threatening aspects of these activities and processes to the wildlife of the Kimberley region.

Frequent, extensive and very hot fires in the Kimberley affect its ecosystems in several ways. They change the structure and composition of vegetation, endangering some species of plants and removing important wildlife habitat refugia. They also leave the ground unprotected from the heavy monsoonal rains, causing soil erosion and later stream sedimentation.
PHOTO: ROBIN CHAPPLE

FIRE

Inappropriate fire regimes pose a threat to biodiversity in the Kimberley and across northern Australia (e.g. Bowman *et al.* 2001; Russell-Smith *et al.* 2003). Historically, Indigenous people managed fire throughout the region, which included fine scale prescribed burning across a variety of vegetation types and around important cultural and food resource sites, such as rainforest patches. This most likely resulted in a mosaic of burnt and unburnt vegetation and provided buffers against unplanned wildfires around critical biodiversity refuges (Environmental Protection Authority 2006). These fire patterns have been replaced in the past few decades with one that is increasingly dominated by extensive and intense mid to late dry season fires. As a consequence, the mean age (and variance) of the vegetation has declined (Legge *et al.* 2010).

Altered fire regimes interacting with other degrading processes, especially over-grazing, have led to structural and floristic change in vegetation, declines in vegetation cover and critical resources such as tree hollows. They are also associated with increased soil erosion after heavy rains (doubled erosion rates have been recorded in similar situations in the Top End of the Northern Territory (Townsend and Douglas 2000), leading to increased sedimentation in stream beds. These changes have severe negative impacts on native flora and fauna (Vigilante and Bowman 2004; Legge *et al.* 2008). Extensive flat savanna areas are more vulnerable to large intense fires, as there are fewer inflammable refugia such as rocky areas. Without appropriate management, the impacts of fire are likely to increase as the region is predicted to become even more fire prone with ongoing climate change (Dunlop and Brown 2008).

INTRODUCED HERBIVORES

Most of the Kimberley is currently under pastoral lease, with cattle being the domestic stock. Grazing impacts in the Kimberley are made up of a mix of managed and feral cattle, feral horses and donkeys. These stock occur across all tenures, including national parks. The southern part of the Kimberley region is most severely affected by introduced herbivores, particularly woodland, wetland and riparian habitats, while large areas such as the coastal fringe remain relatively ungrazed.

The main impacts of introduced herbivores in the Kimberley are evident at the herbaceous understorey layer; the tree layer exhibits a higher degree of integrity. Specific impacts include compaction of soil, loss of grazing-sensitive plant species, reduced biomass in the grass layer, introduction of weed seeds, trampling of seedlings and mature plants as

LEFT
Donkeys are amongst the introduced herbivore species that contribute to grazing impacts in the Kimberley. In recent years concentrated management efforts have substantially reduced the populations.
PHOTO: ANITA HEATHCOTE/ AUSTRALIAN WILDLIFE CONSERVANCY

RIGHT
Cattle and other large introduced herbivores damage wetlands by trampling fragile vegetation and churning the mud.
PHOTO: WAYNE LAWLER/ AUSTRALIAN WILDLIFE CONSERVANCY

well as ring-barking of trees. Trampling also leads to erosion and sedimentation, particularly in wetlands and riparian areas where stock congregate (Vernes 2007). Many of the effects on biota are similar to those caused by fire, particularly the widespread loss of vegetation cover (leading to increased predation of small native animals), reduction of structural habitat and food resources (limiting fecundity and survival) (Legge *et al*. 2011). Erosion is particularly damaging to native riparian and freshwater species. The introduction of non-native pastures in some areas is further affecting vegetation composition and structure as well as increasing fire intensity and frequency (Environmental Protection Authority 2006).

INVASIVE PLANTS

Infestations of non-native plants are another threat to biodiversity in the Kimberley. The Kimberley region's weed problems are serious but localised and the threat of introduction of new weeds increases with development of the region. Some invasive plants were introduced for pastoralism, agriculture and horticulture, while others were introduced accidentally by vehicles, heavy machinery, boats and people. Invasive plants are often associated with certain fire and grazing regimes (Environmental Protection Authority 2006; Environs Kimberley 2008). Several species such as buffel grass *Cenchrus ciliaris*, grader grass *Themeda quadrivalvis* and Gamba grass *Andropogon gayanus* are advantaged by frequent fire and may increase the intensity of fire dramatically. For instance, Gamba grass burns with up to eight times the intensity of native grasses (Environmental Protection Authority 2006). Thus far, Gamba infested areas of the Kimberley are small in comparison with the extensive areas affected in the Top End of the Northern Territory. Invasive plants also compete with native grasses, reducing food resources for wildlife and contributing to habitat homogenisation. Some weed species such as *Calotropis procera* colonise after disturbance such as heavy grazing and/or fire (Start 2010).

INVASIVE ANIMALS

Invasion by feral predators has contributed to range reductions and population declines of many native animals in Australia; small to medium sized mammals have been particularly affected. The primary feral predator in the Kimberley is the domestic cat. Cats have possibly been present in the region since the 1880s and were established by the 1920s (Abbott 2002). The number of cats occurring in the Kimberley is unknown due to difficulties in survey, although a radio-tracking study at Mornington Wildlife Sanctuary suggests there is one individual per 3 km^2, each eating 5–12 native vertebrates daily. If this population density of cats occurred throughout

LEFT
Parkinsonia *Parkinsonia aculeata* is one of Australia's 20 'Weeds of National Significance'.
PHOTO: RIEKS VAN KLINKEN

RIGHT
Feral cats consume small native animals, though difficulties in trapping cats have limited the collection of data on their impacts on wildlife.
PHOTO: AUSTRALIAN WILDLIFE CONSERVANCY

the region there would be over 100,000 individuals present, consuming at least 500,000 native animals every day (Legge unpublished data).

There is some evidence that dingoes, as a top predator, can help control the negative effects of smaller predators like foxes and cats (Glen *et al.* 2007; Johnson and VanDerWal 2009; Letnic *et al.* 2010; Kennedy *et al.* 2011). The regular baiting of dingoes is therefore likely to exacerbate the problem of introduced feral predators (Wallach *et al.* 2010).

Cane toads are a new arrival in the region, invading from the east, poisoning native predators such as quolls, freshwater crocodiles, goannas and snakes, and competing with and preying upon native fauna (Glen and Dickman 2008; The Government of Western Australia 2009; Department of the Environment 2010; Shine 2010).

MINING, AGRICULTURAL & TOURISM EXPANSION

While currently not pervasive in the Kimberley like the above threats, development activities have the potential to be ecologically damaging, depending upon the scale and nature of operations. The Kimberley region is subject to many mine leases for minerals such as bauxite and precious gems, and is currently subject to oil and gas explorations. Bauxite mining has the potential to destroy vegetation and soils. There is a high correlation between the distribution of the deposits and some vegetation communities such as tall *Eucalyptus tetrodonta* woodlands. Indirect effects of mining, mineral processing and associated energy production can include large-scale extraction of groundwater, contamination of waterways and the creation of roads and increased settlement, which may exacerbate the problems of feral animals, weeds and uncontrolled wildfire. If invested effectively, off-setting arrangements from development activities have the potential to create biodiversity benefits.

The Northern Australia Land and Water Taskforce found low potential for large-scale sustainable expansion of agriculture, but political and economic interest in the idea of northern Australia as a 'food bowl' of Australia remains, particularly for increasing the intensity of pastoral use (Stone 2009). Large-scale increases in agriculture could result in direct losses of terrestrial habitats, especially in fertile areas which are important as biodiversity refugia during dry periods (Morton *et al.* 1995). Further, it may require the extraction of large quantities of water. Information on the effects of large scale water extraction is severely limited, especially in the face of changing climates, but it may have detrimental impacts on both freshwater and terrestrial ecology of the region (CSIRO 2009).

The burgeoning tourism industry of the Kimberley can potentially contribute to threats, particularly in the absence of ecotourism regulation. These threats include increased fire risks, the introduction of exotic species and associated infrastructural development, in addition to impacts on culturally important sites (Wunambal-Gaambera Aboriginal Corporation 2001; Yu and Yu 2003).

HYDROLOGICAL CHANGE

The Kimberley has an extensive river and stream network influenced primarily by tropical monsoonal rainfall. The region has very few examples of perennially flowing rivers; most dry up to a series of disconnected pools during the long dry season. During this time, rivers and permanent waterholes are maintained by groundwater (CSIRO 2009). Where these semi-perennial watercourses do exist, they are vital assets (refugia hotspots) because of their unique flow and ability to support important

Rainfall in the Kimberley is highly seasonal. During the wet season the rivers swell and waterfalls surge, such as here at Mitchell falls.
PHOTO: ROD HARTVIGSEN, MURRANJI PHOTOGRAPHY

ecological assemblages. Hydrological connectivity, both laterally and longitudinally, is very important for both in-channel and floodplain processes. In the Kimberley region, seasonal river discharges are critical ecological processes that drive coastal and marine ecosystems. Outside of the Ord and Fitzroy Rivers, key hydrological processes remain largely unaltered (Start and Handasyde 2002; Morgan *et al.* 2005; Department of Water Western Australia 2009a; Kirby *et al.* 2009), but this could change with industrial and agricultural development of the Kimberley (CSIRO 2009).

Extraction of either surface or groundwater for agriculture or other developments such as mining poses threats to wetland and stream biota (Vernes 2007) and critical waterholes on which large numbers of species rely during the dry season. Broadscale soil and vegetation degradation through over grazing and excessive fire causes changes in recharge and runoff rates. These changes spill over into the marine environment because of the strong links between freshwater and marine aquatic systems in the Kimberley as a result of the extreme tidal influence linking these two environments (Mustoe and Edmunds 2008).

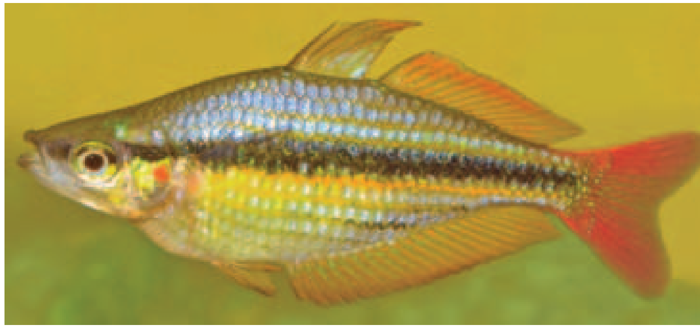
Current conservation management

Conservation management in the Kimberley is characterised by the region's remoteness, the associated lack of formal ecological data and the thin spread of available management resources and operational capacity over a vast area with diverse tenure types (*Figure 2* on page 16). All land tenure types in the Kimberley contain wildlife species and important ecological processes. Most of the region is under pastoral leases (some owned and managed by Indigenous people, some with a co-existence of native title and pastoral lease), Aboriginal reserves and unallocated crown land. Currently only a small proportion (approximately 11%) of the Kimberley in Western Australia is designated as protected areas. The amount of land protected varies greatly by bioregion: North Kimberley, 15%; Central Kimberley, 12%; Dampierland, 1%; Victoria Bonaparte, 6%; and Ord Victoria Plain, 16% (Commonwealth of Australia 2008). This protected area estate is substantially smaller than that of the Top End (Watson *et al.* 2009), which has been shown to be grossly inadequate to protect wildlife species in the long-term (Woinarski and Hickey unpublished). This highlights the need for increased conservation management and protection of the broader landscape in the Kimberley (Soulé *et al.* 2004).

There are many groups involved in carrying out work relevant to wildlife conservation in the Kimberley region, including governments at three levels, non-government organisations, Traditional Owners, pastoralists and other landholders. The total investment is estimated to be in the order of $20 million annually[2].

The state government, mainly through the Western Australian Departments of Environment and Conservation (DEC) and Agriculture and Food (DAFWA), is involved in activities such as weed control, pest animal management, quarantine, fire management and scientific research. For example, donkeys have now been effectively controlled over much of the region in a targeted program carried out by DAFWA. Other state-based agencies committing resources to management include the Fire and Emergency Services Authority, which is involved in various projects to avoid uncontrolled late dry season fires; Western Australia's Natural Resource Management (NRM) which provides grants to a range of projects relating to land management and research; and the Department of Water which is involved in projects related to education and waterway recovery. The Western Australian state government has committed to establishing a larger system of protected areas across land and sea in the northern Kimberley, as well as increased funds over three years for conservation management (Government of Western Australia 2010). Local governments are also supporting a range of projects relevant to biodiversity conservation.

The Australian Government also supports a variety of NRM activities including cooperative efforts in fire, invasive species, water and grazing management for habitat protection and maintaining ecosystem functions. The Rangelands NRM body is involved in this work collaboratively with a range of Kimberley stakeholder groups, for example, as part of the EcoFire project. Quarantine is another activity supported by both the Western Australian and Australian governments, which is aimed at preventing new threats caused by invasive plants and animals. This involves surveillance and



Western Rainbow Fish *Melanotaenia australis* are widely distributed through the Kimberley. They disperse when pools become connected during the wet season.
PHOTO: NEIL ARMSTRONG

2 This estimation of current investment has been made from both published and unpublished sources from a wide range of institutions, including some personal communications made in confidence. It is important to note that much of this investment is for natural resource management but is likely to have associated benefits to wildlife. Further, some of these funds are spent outside our study area on the Kimberley islands.

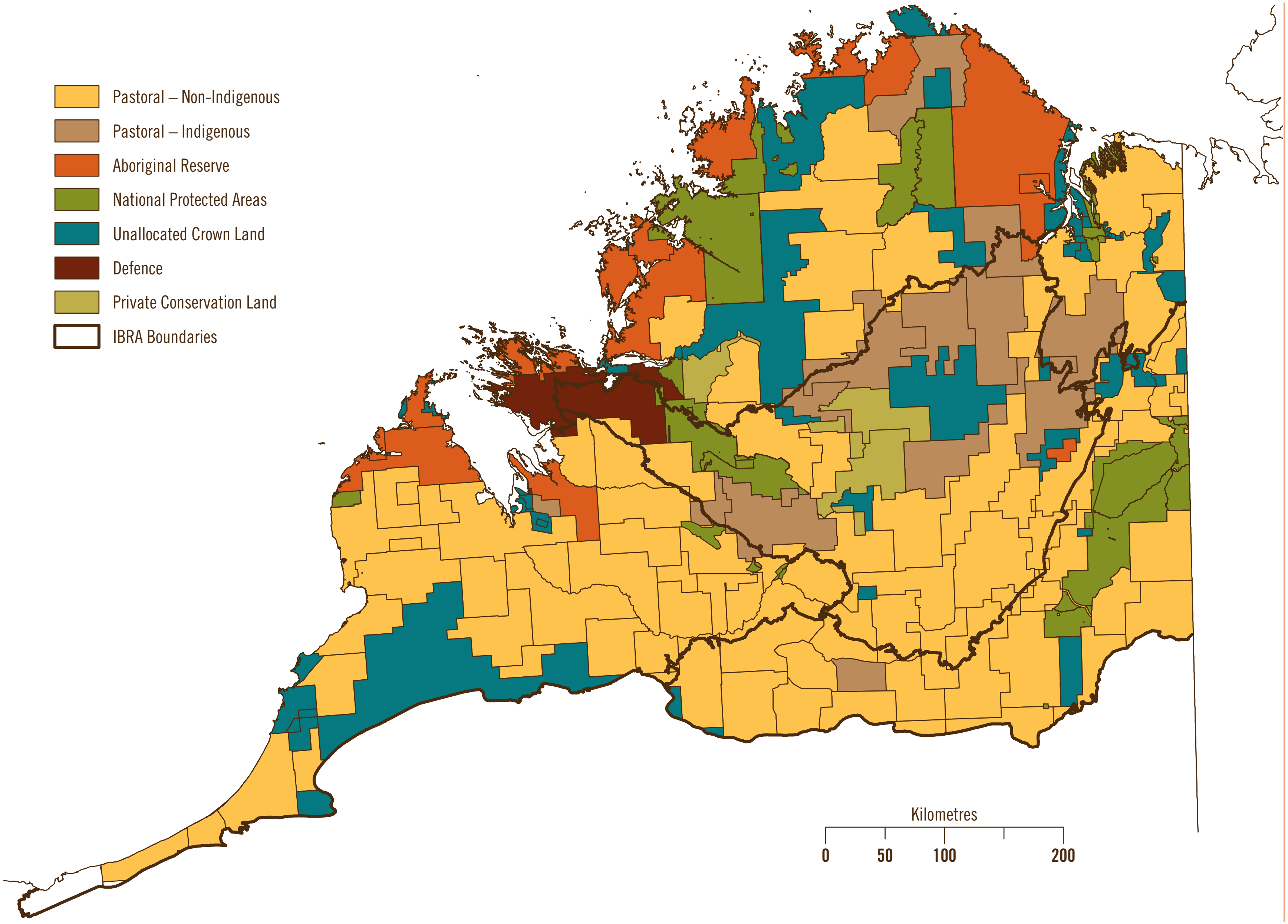


FIGURE 2
Distribution of various land tenure types in the five bioregions of the Kimberley.

control at the region's air and seaports as well as interstate boundaries. The Australian Government also supports Indigenous land management and is currently in ongoing consultation on the establishment of Indigenous Protected Areas in eight locations in the Kimberley region.

Management and planning by Indigenous landholders (pastoral properties, Indigenous Protected Areas (Commonwealth of Australia 2010) and other lands) is a crucial component of conservation across northern Australia (Woinarski *et al.* 2007). Various Traditional Owner groups and Aboriginal Corporations are involved in initiatives to manage country. For example the Balanggarra and Wunambal-Gaambera Aboriginal Corporations developed a vision and plan for managing their country in their own terms, with support from the Tropical Savannas Cooperative Research Centre (Wunambal-Gaambera Aboriginal Corporation 2001). The Australian Government funds the Working on Country program, which is run by the Kimberley Land Council (Kimberley Land Council 2010) to support Indigenous rangers. These rangers are involved in a variety of land management activities, creating links between organisations. For example the Yawoorroong Miriuewung Gajerrong Yirrgeb Noong Dawang Aboriginal Corporation manages six regional parks for conservation under the Ord Final Agreement (Yawoorroong Miriuwung Gajerrong Yirrgeb Noong Dawang Aboriginal Corporation 2010). The Indigenous Land Corporation, which is a statutory authority, also provides support for a variety of activities involving Indigenous rangers in the region.

Conservation management efforts are also being made by non-government organisations. The Australian Wildlife Conservancy is the largest private holder of conservation land in the Kimberley, contributing substantially to the protected area estate in the region, and carries out a combination of conservation management and research. In cooperation with other agencies and landholders, the Australian Wildlife Conservancy has implemented a successful fire management strategy over an area of five million hectares, coordinating management on their own properties at Mornington and Marion Downs and eleven of the surrounding pastoral and Indigenous pastoral leases. Environs Kimberley has been involved in activities such as working with Traditional Owner groups to develop and implement management of monsoon vine thickets. WWF Australia has coordinated various projects that involve communities in recording ecological values such as wetland condition and coastal and marine environmental and cultural values. Other groups involved in supporting or implementing projects in the region include the Pew Environment Group, The Nature Conservancy, Bush Heritage Australia and the Australian Conservation Foundation. Other groups such as Toadbusters and Ord Land and Water are focused on particular management issues or areas.

Much of the land in the Kimberley is under private management, particularly as pastoral properties. Some pastoral management activities, such as weed control and fire management, also have benefits for wildlife conservation and a number of pastoralists manage their land to enhance wildlife benefits and gain a secondary income from ecotourism. There is financial assistance for some conservation management on private land from government programs and non-government organisations, but a large amount of work is financed by landholders.

As rubber vine *Cryptostegia grandiflora* is a Weed of National Significance, it is a priority for control efforts. PHOTO: DEPARTMENT OF ENVIRONMENT AND CONSERVATION WA

Brolgas *Grus rubicunda* dance on the banks of the Fitzroy River.
PHOTO: GLENN WALKER

THE NEED TO PRIORITISE THREAT MANAGEMENT

While current conservation efforts in the Kimberley are valuable, ongoing decline in ecosystem health and wildlife populations indicates that these actions are inadequate to overcome the region's conservation challenges. Increased and effective efforts in protection and conservation management at the landscape scale, maintained over the long term, are required to avoid multiple wildlife extinctions within the next 20 years (Fitzsimons *et al*. 2010; Woinarski *et al*. 2011). What is not known, however, is the funding required for such management and how it should be best spent to retain functioning wildlife populations in the Kimberley. While the creation and management of protected areas is often the cornerstone of conservation strategies, most threats operate over large landscapes irrespective of tenure. There is increasing recognition of the importance of whole landscape management for the persistence of species and ecological processes (McIntyre *et al*. 2002; Soulé *et al*. 2004; Mackey *et al*. 2007). Northern Australia, including the Kimberley, is one region where management both inside and outside protected areas has been identified as both possible and essential (Woinarski *et al*. 2005; Woinarski *et al*. 2007).

The Stripe-faced Dunnart *Sminthopsis macroura* is one of many native mammal species that are threatened by changed fire patterns, introduced herbivores and feral cats.
PHOTO: STEVE MURPHY/ AUSTRALIAN WILDLIFE CONSERVANCY

There are often differences in the costs and benefits of actions for abating threats to biodiversity. Conservation or threat management actions should be evaluated by predicting their importance for achieving pre-specified objectives (Vane-Wright *et al.* 1991; Margules and Pressey 2000; Possingham *et al.* 2006). Such rational decision making in conservation began with the emergence of classic protected area design theory. In this process, sets of potential protected areas are selected to collectively meet targets for a range of biodiversity features, for example, to protect 30% of the habitat of each species, at a minimal cost (Possingham *et al.* 2000). Where multiple conservation actions are considered, they can be ranked by their cost-effectiveness, where the benefits of each action (usually measured in non-dollar terms) are divided by the costs (Levin and McEwan 2001; Cullen *et al.* 2005). The benefits of actions can be measured as the improvement in species habitat protected (Carwardine *et al.* 2008) or improvement in species persistence (Bottrill *et al.* 2008; Joseph *et al.* 2009), and the costs are usually financial management costs and/or opportunity costs (Naidoo *et al.* 2006). Results of a cost-effectiveness analysis are specific to the weights and parameters used by those conducting it, which are not necessarily shared by others. In reality a range of benefits or costs outside those used in an analysis are likely to be associated with an action. For example, Possingham *et al.* (2002) show that targeted conservation actions in Australia provide benefits to employment, improved livelihoods, improved health, reduction in greenhouse gas emissions and more.

In many ecologically important regions, an urgent need for conservation action is hampered by a lack of formal data on species distributions and likely responses to threats and management actions. An important body of research focuses on methods for undertaking conservation management appraisal and prioritisation using the knowledge of experts to complement formal scientific data (Martin *et al.* 2005; Kuhnert *et al.* 2010). In many cases it appears better to make decisions using expert knowledge alone, rather than to avoid decisions for lack of data. For example, Possingham *et al,* (2002) used expert information to evaluate the cost-effectiveness of a range of actions for saving threatened species in Australia. This helped to justify the implementation of many of their recommended actions, including ending Queensland's broadscale vegetation clearing, which occurred soon afterwards. A similar approach is used in New Zealand to prioritise threatened species recovery projects (e.g. Joseph *et al.* 2009), using expert predictions of improvements in species persistence for respective actions divided by the action's cost. This approach achieved markedly higher biodiversity outcomes per dollar spent, compared with prioritising actions by threat status or public values alone. These real world conservation planning assessments would have taken far longer had the authors waited for sufficient empirical data to be formally collated, thus delaying the implementation of the actions they recommended while biodiversity continued to decline.

Sandy beach of Moll Gorge, where the Hann River cuts through the Phillips Range, Marion Downs Wildlife Sanctuary.
PHOTO: WAYNE LAWLER/ AUSTRALIAN WILDLIFE CONSERVANCY

PROJECT AIMS AND SCOPE

This project strives to provide a rational framework for underpinning the cost-effective management of landscape scale threats to wildlife in the Kimberley. The approach builds on the method presented by Possingham *et al.* (2002) which uses expert information to estimate the biodiversity benefits, feasibility and costs of key conservation management actions, in order to appraise their cost-effectiveness. We evaluate a range of feasible conservation management actions directed at broadscale current threats to mainland terrestrial vertebrate wildlife. While many of the management actions discussed have been previously recommended (e.g. Nature Conservation Service 2009), we provide new information on their costs, feasibility and likely benefits to wildlife, and integrate these factors in a rational and defensible framework to estimate their cost-effectiveness.

Specifically the project aims to:

- Recognise key ecological values of the Kimberley and what sustains them, particularly in relation to wildlife and their habitat requirements
- Develop a costed suite of conservation actions to address threats to Kimberley wildlife
- Provide information on the likely wildlife persistence benefits of various levels of investment in these management actions and conversely, the likely species losses in the absence of various levels of investment in these actions
- Provide information regarding the management actions for conserving wildlife and other ecological values that promotes the most cost-effective application of conservation investments
- Ensure the approach is able to consider, or inform analyses which consider, information outside that used in this analysis
- Provide outputs and information designed to be useful to a range of decision makers, groups and individuals.

We acknowledge that many factors other than the needs of wildlife come into play in conservation decision making. We recognise the great importance of the priorities of local land owners and users, including Indigenous people, pastoralists and the mining and tourism sectors. However, we were unable to collect and analyse information on Indigenous knowledge, preferences, social considerations and cultural values. Engagement with other groups was similarly outside the project scope. Further, the current study focuses on terrestrial and marine interface environments, but does not explicitly consider the critical connections between these and marine environments. Finally, it is likely that our results present a best case scenario, as we consider some of the key current sources of damage to the region without evaluating other possible future threats, such as climate change. The addition of further threats is likely to compound the effects of the threats evaluated in this report.

Rather than presenting final decisions, we aim to support decision makers (Traditional Owners, government agencies, pastoralists, the conservation sector and others) to plan and gain resources for implementing management strategies for conserving wildlife in the Kimberley.

The Frill-necked Lizard *Chlamydosaurus kingii* is relatively abundant in northern Australia, but this iconic reptile is now at risk of decline due to predation by feral cats.
PHOTO: RAY LLOYD

Star Finches
Neochmia ruficauda
near Fitzroy Crossing.
PHOTO: BRUCE DORAN

THE CONSERVATION MANAGEMENT APPRAISAL APPROACH

Collating expert information

While formal survey data of the Kimberley region are incomplete, regional experts in western ecological science, Indigenous knowledge and land management, collectively hold a wealth of knowledge of its ecology and natural resource management. As part of this project, some of these experts in ecology and land management shared their knowledge through two formal workshops and follow-up conversations (by phone, email and in person) which were supplemented where possible with empirical data. The appropriate gathering and incorporation of Indigenous knowledge requires approaches that were beyond the resources and thus scope of this project. The approach taken here is a scientific one and we acknowledge that this is just one of many perspectives that need to be considered in a comprehensive conservation plan. Details on the expert elicitation process are found in *Appendix 1* on page 53.

The first workshop included a group of ecologists with extensive field-based experience in the Kimberley's flora and fauna. The group defined the study area as the IBRA bioregions of North Kimberley, Central Kimberley, Dampierland, Victoria Bonaparte and Ord Victoria Plain within the Western Australian state borders (*Figure 1* on page 9). Bioregions were chosen as the primary spatial unit for consideration of wildlife persistence as the paucity of data made it difficult to make reliable estimates at a finer spatial resolution. The group defined key threats to biodiversity in these regions on an ecosystem basis and their paths of influence on the biota of the Kimberley (see *Appendix 2 on page 56* for details). They then identified key management actions available to overcome these threats, which were:

1. combined fire and introduced herbivore management (these could not be separated in terms of their benefits to wildlife)
2. weed management (eradication, control and quarantine)
3. introduced predator control (i.e. cats).

Ducks take flight at Parry's Lagoon, Parry's Lagoon Nature Reserve.
PHOTO: GLENN WALKER

Other threats such as the invasion by cane toads and ecologically inappropriate development were also considered, with the acknowledgement that feasible actions for these threats are not well known or were outside the scope of the study.

Species with comparable ecosystem and habitat requirements including feeding, shelter and nesting resource requirements are likely to respond similarly to threats and therefore conservation actions to abate threats (Isaac and Cowlishaw 2004). Experts defined key ecosystem types and species groups in the Kimberley. The ecosystem types are:

- non-rugged savanna
- rugged savanna (on rugged sandstone)
- riparian/in-stream
- wetlands (including springs and seeps)
- rainforest
- coastal (mangroves with adjacent flats and dunes)
- islands (islands were not assessed).

The non-coastal ecosystems were considered to be embedded within a matrix of rugged and non-rugged savanna. Islands were not assessed as experts were not confident in estimating persistence of wildlife at the time of study and because many of the threats to islands are different from the mainland. Ongoing work by the Department of Environment and Conservation is indicating that previous records of fauna on these islands have been very incomplete. This work is also demonstrating the important role of islands as sanctuaries for numerous species as many of the Kimberley's thousands of islands are insulated from some of the most severe threats facing mainland biota (Conservation Commission of Western Australia 2010).

TOP
Non-rugged savanna forms one of the important 'matrix' ecosystems. Management of this ecosystem type dramatically affects the condition of other embedded ecosystems such as wetlands. Mornington Wildlife Sanctuary.
PHOTO: TARA MARTIN

BOTTOM
Savanna on rugged sandstone is the other important matrix ecosystem. Its rocky substrates provide wildlife with refuge from fires. Boab Valley surrounded by the rugged Phillips Range, Marion Downs Wildlife Sanctuary.
PHOTO: WAYNE LAWLER/ AUSTRALIAN WILDLIFE CONSERVANCY

Within these ecosystems, the experts defined 21 non-mutually exclusive 'ecological groups' with similarities in the ways they use habitat and food resources. These groups in the savanna are:

- hollow/tree structure dependent (divided into volant and non-volant)
- rock dwelling
- ground surface and burrowing (divided into 'critical weight range' mammals and others)
- litter dwelling
- granivores
- insectivores
- frugivores
- nectarivores
- herbivores
- predators.

And in other ecosystems:

- riparian specialists
- in-stream specialists
- rainforest frugivores
- other rainforest specialists
- aquatic wetland specialists
- terrestrial wetland specialists
- coastal specialists (divided into arboreal, ground surface and burrowing, and water birds).

For each of these groups, experts estimated the average probability that species would persist at functional levels for at least 20 years (this was considered a reasonable medium term time frame for reviewing the effectiveness of conservation), under a no management scenario, and then assuming the implementation of specific management actions. The interactions between actions were noted as an

TOP
Riparian ecosystems are critical for specialist species such as the Purple-crowned Fairy-wren *Malurus coronatus*, as well as providing refuge for a broader range of wildlife in the dry season. Associated in-stream areas are critical habitat for freshwater specialists like the many species of endemic rainbow fish. King Edward River.
PHOTO: GLENN WALKER

BOTTOM
Wetlands are important ecosystems for many specialist species but are also refugia for other more wide-ranging fauna during the dry season. Some wetlands are fed by groundwater at these times. Parry's Lagoon.
PHOTO: GLENN WALKER

important consideration. An example of the matrix detailing this information is shown in *Appendix 1* on page 53.

The second workshop involved participants with extensive experience in practical management in the region. The group defined the elements of the proposed conservation management actions, their goals and the measures required to achieve them. The likely financial costs based on recent experience were estimated over a 20 year period and recorded in present value terms as minimum and maximum costs, once-off costs, ongoing costs per hectare, or costs per property. The group differentiated between regions, tenures and management models where applicable, so resultant total costs differed for each action-bioregion combination. These costs did not account for changes in conditions such as severe climate change or technological development.

For each of the conservation actions, we asked the experts to estimate, on a scale of 0–100%, the 'feasibility', or the likelihood that the action could be carried out successfully under current conditions. Using this scale throughout the elicitation provided a benchmark and helped avoid inconsistencies in logic as the elicitation progressed. Future developments and social change may either increase or decrease this feasibility of acting in the future. It was noted that some actions may not have direct benefits to biodiversity, but increase the feasibility of other actions. Some enabling actions, such as changing land tenure or policy, were noted but not included in the quantitative analysis. Finally, the group listed other potential benefits that would be generated by implementing each action, such as carbon sequestration, improved water quality or job creation. These other benefits were discussed rather than used in the quantitative analysis.

Analysis

Following the workshop, we generated lists of wildlife species in the Kimberley, using data from McKenzie *et al.* (2007) on mammal distributions and Naturemap (Department of Environment and Conservation) as a basis for bird, reptile and amphibian distributions, and the Australian River Institute (Kennard 2010) for fish distributions. We recorded the bioregions in which each species occurs and which ecological groups, based on food and habitat use, they fall within. At least one expert on each taxon checked these lists for accuracy. Many species fell within more than one group, for example the Sugar Glider *Petaurus breviceps*, is both a nectarivore and a hollow dependent species. Species that fell into more than one group were assigned to the group which was most vulnerable to each threat, by the rationale that species respond to losses and gains in the resource that is most limiting to their survival under each threatening process.

We calculated the total cost in each bioregion, of carrying out each action:

1. fire and introduced herbivore management
2. weed management
3. introduced predator control
4. all actions 1–3.

Each action included several activities (*Table 1* on page 28). More details of each of these actions and issues associated with their implementation, are provided in *Appendix 4* on page 64.

We estimated the cost of carrying out each activity over the areal extent of each bioregion. We first separated costs that would be incurred once off, such as building a fence, from those that would

Rainforest patches are important refugia habitat for a suite of wildlife species, as well as core habitat for many plants and invertebrates. El Questro Wilderness Park.
PHOTO: GLENN WALKER

require ongoing funds, such as maintaining the fence. We multiplied the tenure-based per hectare costs by the total area under each tenure in each bioregion. We multiplied costs that were estimated at the property scale by the number of properties in each bioregion. For actions that would be carried out across all bioregions, such as a regional weed management program, we divided the total cost equally amongst all the bioregions, regardless of their size. For ongoing costs, we determined the total cost now of carrying out the action over 20 years, using a discount rate of 2% per year (this is a low discount rate used commonly for government planning). We then added the costs of each activity (*Table 1* on page 28) for both once off and ongoing costs, to determine the total cost of carrying out all the activities in each region over 20 years. For each suite of actions we took the mean predicted feasibility of the constituent actions as an indication of the suite's overall feasibility.

TOP
Coastal ecosystems cover mangroves and their associated flats and dunes. Rocky coastal flats, Beagle Bay.
PHOTO: GLENN WALKER

BOTTOM
Offshore islands are particularly important for conservation in the Kimberley as many are protected from the most damaging impacts of weeds, inappropriate fire regimes, grazing and feral predators. Buccaneer Archipelago.
PHOTO: GLENN WALKER

Table 1: Key management actions: their objectives, the activities involved, costs and their feasibility of implementation.

Action	Objectives	Activities required*	Costs	Feasibility (range or average %)
1. Fire and introduced herbivore management **1a.** Implement appropriate fire management	Increase number of clumps with 3+ year old post-fire vegetation over entire region Reduce significantly the size of single fire events over entire region	Develop fire management plan for each tenure (pastoral, Indigenous, DEC and EcoFire were considered separate management models)	$0.10–0.30/ha/year depending upon land tenure and geographic location (slightly higher in northern Kimberley)	50–100%
		Aerial control burning in late wet season and early dry season		50–100%
		Fire-scar monitoring and analysis		100%
		On-ground burning in focal areas and around assets	$0.10–0.40/ha/year depending upon land tenure and geographic location (slightly higher in southern Kimberley)	50–100%
		Targeted fire suppression	$0.10/ha/year	50–100%
		Build relationships and capacity with land holders	$2–2.25 million/year for each land tenure type	NA
		Education about inappropriate fire management, enforcement of regulations		
1b. Manage domestic and feral cattle, plus manage other feral herbivores	Manage grazing pressure such that biodiversity is not adversely impacted, maintaining ecological function Reduce impacts in sensitive areas	Pastoral tenure: define best management practice and develop a management plan	$10,000/property, once off	85%
		Pastoral tenure: extension/education about sustainable grazing generating higher profits (and achieving successful outcomes by this)	$3,000/property, once off	15%
		Non-pastoral tenure: develop a management plan which includes land holders, raises awareness, provides employment, provides incentives to remove animals, provides options to sell or use animals, considers relationships between people and introduced animals, considers ethics	$10,000–20,000/ group of land managers, once off	85%
		All tenures: manage stock access using fences, water, fire	$300,000–500,000/ property, once off + 10%/year ongoing	85%
		All tenures: fence, muster, trap, remove feral herbivores (shooting where appropriate), using approaches shown to be effective e.g. Judas donkey program, pig trap system used on Cape York Peninsula	$0.15/ha/year on average (focused on preferred habitat such as along waterways)	85%

* BIOREGION ABBREVIATIONS USED: NORTH KIMBERLEY (NK), CENTRAL KIMBERLEY (CK), DAMPIERLAND (DL), VICTORIA BONAPARTE (VB), ORD VICTORIA PLAIN (OVP)

Action	Objectives	Activities required*	Costs	Feasibility (range or average %)
2. Weed management	Prevent invasion by new weeds and coordinate management (all regions)	Early detection and monitoring program (build on existing Northern Australia Quarantine Strategy program)	$800,000 once off + $150,000/year ongoing	100%
		Weed management strategy: workshop to liaise across groups and surveillance package, four full time positions and support for an Indigenous ranger program	$200,000 once off + $600,000/year on going	75%
	Eradicate certain Weeds of National Significance (in regions specified)	Gamba grass *Andropogon gayanus*, eradicate within five years: search and spray, focus on creek lines (DL)	$500,000 once off + $10,000/year ongoing	75%
		Mesquite *Prosopis spp*: search and spray (DL, OVP)	$10,000/year ongoing	50%
		Rubber vine *Cryptostegia grandiflora*: pull out, herbicide, fire (two locations in DL and OVP)	$500,000/year ongoing	50%
		Acacia nilotica: search, herbicide, fire (west of Wyndham, VB)	$1,000,000 over 5 years	50%
		Mimosa pigra: remove one patch near Kununurra (VB)	$5,000–10,000/year ongoing	100%
	Contain and control other key weeds (in all regions, unless specified)	Grader grass *Themeda quadrivalvis*: start-up equipment, ranger costs, aerial survey (Roadsides, e.g. Gibb River Road, southwest of Wyndham, VB, OVP)	$500,000 once off + $400,000/year ongoing	50%
		Parkinsonia aculeata: biocontrol (moth) and herbicide, eradicate in some areas, contain in others	$200,000/year ongoing	75%
		Stinking passionfruit *Passiflora foetida*: fire, biocontrol	$2,000,000 over 5 years	25%
		Neem *Azadirachta indica*: herbicide, basal spray, pull juveniles	$1,000,000 over 5 years	75%
		Bellyache bush *Jatropha gossypiifolia*, rubber bush *Calotropis procera*, butterfly pea *Clitoria ternatea*: identify realistic containment lines (catchments), map, plan, herbicide, cut and paste, good land management	$200,000 once off + $1,000,000/year ongoing	75%
		Trees like poinciana *Delonix regia*, raintree *Koelreuteria elegans* ssp. *formosana*, chinee apple *Ziziphus mauritiana*: mapping, control	$200,000 over 5 years	75%
		Buffel grass *Cenchrus ciliaris*: control around key conservation assets	$1,000,000 over 5 years	25%

* BIOREGION ABBREVIATIONS USED: NORTH KIMBERLEY (NK), CENTRAL KIMBERLEY (CK), DAMPIERLAND (DL), VICTORIA BONAPARTE (VB), ORD VICTORIA PLAIN (OVP)

Action	Objectives	Activities required*	Costs	Feasibility (range or average %)
3. Control of key introduced predators (cats)	Increase dingo numbers	Education to eliminate dingo baiting	$1,000,000 over 5 years	25%
		Compensation per property for animals killed by dingoes	$10,000/property/year	25%
	Directly reduce cat numbers	Educate for spaying cats and controlling their access, and free spaying service (including one full time position)	$150,000/year over entire region	25%
	Improve knowledge	Research on cat ecology and treatment, including biocontrol	$12,000,000 over 5 years	25%

* BIOREGION ABBREVIATIONS USED: NORTH KIMBERLEY (NK), CENTRAL KIMBERLEY (CK), DAMPIERLAND (DL), VICTORIA BONAPARTE (VB), ORD VICTORIA PLAIN (OVP)

The cost-effectiveness of each conservation management action for improving wildlife persistence was evaluated by combining the information on benefits, feasibility and costs using the following method:

1. The **potential benefit** to wildlife of each action in a bioregion was estimated by calculating the change in likelihood of persistence for each species when each action is implemented and finding the sum of these benefits for all the species in the bioregion.
2. The total potential benefit of an action in a bioregion was multiplied by the predicted feasibility that the action could be carried out as planned, giving a measure of the **likely benefit**.
3. **Cost-effectiveness** (in terms of improving wildlife persistence) was estimated by dividing this likely benefit by the total cost of the action or suite of actions, where the higher the value the more cost-effective. We also tested an area independent measure of cost-effectiveness, by dividing the likely benefits by the cost per unit area.

Termite mounds are dotted across non-rugged savanna in Mornington Wildlife Sanctuary.
PHOTO: TARA MARTIN

4. Each of the actions in each bioregion was ranked according to its cost-effectiveness. The implementation of all actions together and the implementation of each action across all bioregions were also included in the ranking. See *Appendix 1* on page 53 for more details on the mathematical formulae used in the analysis.

We undertook a sensitivity analysis of each of the parameters (cost, benefits and feasibility) on the cost-effectiveness ranking (see *Appendix 3* on page 63).

Ranking actions by their cost-effectiveness independently gives a prediction of the top actions for maximising wildlife benefits for each dollar spent. However, it does not indicate which combinations of actions are adequate to achieve wildlife persistence. With the assistance of the conservation planning tool Marxan (Ball *et al*. 2009), we investigated which actions are required to achieve two variations of biodiversity goals, which are minimum requirements for wildlife conservation:

1. Avoid functional loss of species, by increasing the persistence of every species to at least 50% in at least one bioregion. A species was considered likely to be lost if its probability of persistence over 20 years is less than 50%.
2. Secure species by increasing the persistence of every species to at least 90% in all bioregions that they occur where possible (for some species probabilities of persistence were not predicted to reach 90% even if all actions considered were implemented; for these species the maximum possible persistence probability was sought). A species was considered likely to persist if its probability of persistence over 20 years is at least 90%.

We extended this analysis by investigating how many species are likely to be lost from one or all bioregions in which they occur if only part of this total budget was available for expenditure on the actions recommended (we used the even but arbitrary thresholds of two thirds and one third of the budget required to meet objective 1). We also predicted how many species are likely to be lost if no funds are spent on the wildlife conservation actions identified, using the information on estimated species persistence, which was refined by experts. For more details on how Marxan was used to undertake this analysis, see *Appendix 1* on page 53.

Australian boabs *Adansonia gregorii* are an icon of the Kimberley. The species is endemic to the Kimberley but all other baobab species are native to Madagascar and mainland Africa.
PHOTO: TRUDY O'CONNOR

Intense late season fire. PHOTO: DEPARTMENT OF ENVIRONMENT AND CONSERVATION WA

PRIORITISATION OF THREAT MANAGEMENT ACTIONS

Appraised and ranked management actions

The conservation management actions we considered varied across the Kimberley in the benefits they were predicted to generate, their feasibility and costs (*Table 2* on page 35). Cost-effectiveness also varied across the actions, but not by orders of magnitude. For most actions, the rank order changed depending upon whether the benefits were weighted by area. Smaller regions often appeared more cost-effective when area was not considered; however, carrying out an action over a larger area produces a greater extent of improved species persistence and thus a greater proportional benefit of contributing to the functioning of the entire landscape.

Introduced predator control was predicted to be the most cost-effective action for further investment over the entire Kimberley region, followed by combined fire and herbivore management, then weed management. The benefit per dollar of introduced predator control was predicted to be highest in Victoria Bonaparte when not weighted by area, but was not particularly high in that region when weighted by area. In North Kimberley, however, introduced predator control was predicted to achieve high benefits per dollar regardless of area. Introduced predator control in North Kimberley was therefore the most robust action to carry out in a single region. While predator control was the most cost-effective action, it was currently considered by the participant experts to have a low feasibility due to the high social value placed on cats and limited progress thus far in implementing broadscale controls in Australia. Feasibility was expected to improve over time with implementation of education about the problems of feral cats, ceasing dingo baiting and research into a feasible biocontrol and the interactions between dingoes and cats.

Fire and herbivore management generated the highest benefits of all the actions (*Table 2* on page 35). It was ranked only moderately highly in terms of its cost-effectiveness over the entire region, due to the fact that the costs are well understood and relatively high. Following predator control, carrying out fire and herbivore management in Victoria Bonaparte was the next most cost-effective single action, although carrying out all actions in this region was slightly more cost-effective. However, Victoria Bonaparte was not predicted to generate a high benefit per dollar for carrying out all actions when the size of the area was considered. A great number of social, economic and cultural factors must be considered when implementing management of fire and herbivores, such as the cultural connections between people and cattle.

Weed management alone was not predicted to generate as large benefits to wildlife as the other actions. This is likely because the weed problem is not considered alarming at this point and because it was difficult to quantify the benefits of keeping out potential new weed invasions. However, the benefits of weed management to the conservation of plants, which were not considered directly in this study, are likely to be much higher. Funds that are already being spent on effective weed management should certainly not be withdrawn – they may be the reason that the problem is not severe. An increase in funds for quarantine is likely to be a cost-effective strategy for long term biodiversity persistence.

TOP
The dingo *Canis lupus dingo* is a naturalised Australian predator. The most feasible action identified for reducing predation by cats is to cease baiting of dingoes.
PHOTO: GLENN WALKER

BOTTOM
Sarah Legge from AWC and Sammy Walker from Tirralintji Community discuss fire management strategies as part of the Ecofire program.
PHOTO: RICHARD KINGSWOOD/ AUSTRALIAN WILDLIFE CONSERVANCY

The sensitivity analysis indicated that the top three ranked actions were reasonably robust to changes in the estimated costs, feasibility and benefit parameters for any one action. Each of these changes to the action in question caused only small changes in rank, with one or two exceptions. The lowest five ranked actions were similarly robust to changes in those same cost-effectiveness parameters. Full details of the sensitivity analysis of ranks are provided in *Appendix 3* on page 63.

Other important actions and threats

Many important actions and threatening processes could not be addressed quantitatively in this report (*Table 3* on page 36). In some cases a feasible conservation management action was not able to be identified, for example, for eradicating cane toads, but there are potential actions that could slow down the invasion. In other cases, the scale of the threats was difficult to quantify, for example, with agricultural expansion and increased tourism. The benefits of some actions cannot be measured directly by our wildlife persistence metric, but are enabling actions that are likely to allow the key actions (*Table 2*) to be carried out more successfully. These include supporting and increasing the Indigenous Protected Area network, purchasing properties for targeted conservation management and seeking to reform policy. Note that it should not be assumed that priorities of Indigenous Protected Areas would align with the priorities we present. However, Indigenous Protected Areas have the potential to lead to improved conservation outcomes and provide benefits outside those used in our quantitative analysis (Altman *et al.* 2009).

A particularly important action to safeguard wildlife from extinctions is the creation of two cat-proof (and possibly cane toad-proof) exclosures. This would protect populations of at least eight mammal species which are particularly vulnerable. An exclosure in North Kimberley (such as on Bougainville Peninsula) would be an obvious choice due to its relative intactness and high numbers of endemic species. Another exclosure in Central Kimberley, for example at Mornington Wildlife Sanctuary, would also allow the potential re-introduction of mammals that have been lost from this part of the region, including the Golden-backed Tree-rat *Mesembriomys macrurus*, the Golden Bandicoot *Isoodon auratus* and the Brush-tailed Possum *Trichosurus vulpecula*.

The protection of water resources for biodiversity is another key conservation management consideration and one that is currently being investigated by a number of initiatives as part of the Tropical Rivers and Coastal Knowledge (TraCK) program (Australian Government 2009). In a state-wide assessment, the Kimberley had the highest concentration of rivers in pristine ecological condition (Department of Water Western Australia 2009b). We were unable to look closely at actions for freshwater systems because of a lack of detailed information and resources. However, we considered some important actions to protect freshwater systems, such as the creation of a fish pass around the barrage on the Fitzroy River (as is currently being planned) and the limitation of water extraction for agriculture and mining.

A further essential consideration is the implementation of a targeted monitoring program to inform state-dependent management and adaptive management. Despite being a region of high conservation importance, the Kimberley has a paucity of formal data on biodiversity. Successful conservation management in the region is impossible without a formal system for evaluating management effectiveness in delivering biodiversity results. Adaptive management methods, where monitoring and data collection are conducted to improve management decisions are essential for informing cost-effective data collection (McDonald-Madden *et al.* 2010a,b).

The Golden Bandicoot *Isoodon auratus* and Golden-backed Tree-rat *Mesembriomys macrurus* were once widespread across northern Australia. Both have now been lost from much of their former ranges but populations remain in the northern Kimberley.
PHOTOS: ANDREW BURBIDGE

Table 2: Appraisal of key conservation management actions for wildlife in each bioregion of the Kimberley – estimated benefits (wildlife persistence improvement), feasibility, costs and cost-effectiveness (CE). The five most cost-effective actions, with and without an area weighting, are shaded in orange.

Management action	Bioregion*	Ha (millions)	# species in region	# species benefited	Benefits (persistence improvement)	Feasibility	Initial cost ($M)	Average annual cost, 20 years ($M)	CE	Rank CE	CE (area weight)	Rank CE (area weight)
Fire & Herbivores	NK	8.41	463	415	101.45	85%	$11.1	$6.0	14.40	11	116.34	9
	CK	7.68	356	356	85.1	95%	$16.7	$6.4	12.71	15	97.57	12
	DL	8.36	471	471	76.85	90%	$18.5	$6.4	10.89	18	87.95	13
	VB	1.90	368	368	61.75	90%	$4.6	$2.2	25.37	4	43.89	22
	OVP	5.52	384	384	65.95	90%	$13.6	$4.3	13.73	13	75.46	15
	All regions	31.86	637	637	391.1	90%	$64.5	$25.2	13.96	12	433.57	3
Weeds	NK	8.41	463	213	5.15	55%	$0.9	$0.4	7.70	19	62.23	17
	CK	7.68	356	177	4.8	55%	$0.9	$0.4	7.18	20	55.09	19
	DL	8.36	471	149	8.15	45%	$1.7	$0.6	5.68	23	45.85	21
	VB	1.90	368	152	8.15	45%	$1.4	$0.6	6.18	21	10.69	24
	OVP	5.52	384	142	7.75	45%	$1.5	$0.8	4.46	24	24.51	23
	All regions	31.86	637	263	34	50%	$6.3	$2.8	6.17	22	191.50	5
Predators	NK	8.41	463	401	50.75	25%	$2.7	$0.4	31.95	2	258.18	4
	CK	7.68	356	350	55.5	25%	$2.9	$0.9	15.50	9	118.96	8
	DL	8.36	471	466	52.1	25%	$2.9	$1.1	12.27	17	99.12	11
	VB	1.90	368	364	41.35	25%	$2.7	$0.3	34.75	1	60.10	18
	OVP	5.52	384	378	43.45	25%	$2.9	$0.9	12.60	16	69.28	16
	All regions	31.86	637	631	243.15	25%	$14.0	$3.5	17.30	8	537.43	2
All	NK	8.41	463	463	154.45	85%	$14.7	$6.8	19.44	5	157.06	6
	CK	7.68	356	356	150.7	95%	$20.5	$7.6	18.78	6	144.16	7
	DL	8.36	471	471	120	90%	$23.1	$8.1	13.40	14	108.23	10
	VB	1.90	368	368	95.6	90%	$8.7	$3.1	27.93	3	48.30	20
	OVP	5.52	384	384	101.3	90%	$17.9	$6.0	15.27	10	83.98	14
	All regions	31.86	637	637	622.05	90%	$84.8	$31.5	17.78	7	552.27	1

* BIOREGION ABBREVIATIONS USED: NORTH KIMBERLEY (NK), CENTRAL KIMBERLEY (CK), DAMPIERLAND (DL), VICTORIA BONAPARTE (VB), ORD VICTORIA PLAIN (OVP)

Table 3: Information on conservation management actions and threats that were not quantitatively appraised.

Action	Activities required	Tenures, regions, locations*	Benefits to wildlife	Costs	Feasibility of actions
Enabling actions	Regulation – pastoral land administration reform	Pastoral tenure in all regions	Increases the feasibility of delivering key management actions (*Table 2*)	$150,000/year for campaigning over a 3–5 year campaign	Low
	Targeted purchase of pastoral leases (need to consider Indigenous Land Use Agreement)		As above	$5–10m/property in the north, more in the south	High
	Stewardship arrangements (covenant)		As above	$1m start up costs + $200,000/year	Low, but higher on IPAs, increase as initial properties are established
	Establishment and strengthening of Indigenous Protected Areas	Aboriginal freehold; Aboriginal Reserve and deed of grant in trust lands; Aboriginal-held leaseholds and existing Protected Areas	As above	Largely covered by IPA initiative	High – this is already a major government priority with Indigenous support
Insurance policies for invasive species	Creating cat-proof and cane toad-proof exclosures	Bougainville Peninsula, NK and/or Mornington, CK	All species that are threatened by cats and cane toads, particularly 'critical weight range' mammals and larger predatory marsupials	$10–20,000 per exclosure to set up + $40,000/km for fence + $200,000/year for management	High
	Island sanctuaries	NK islands	All species that are threatened by cats and cane toads, particularly 'critical weight range' mammals and larger predatory marsupials	$1m–3m/year, including 2–3 ranger salaries	High
Strategic monitoring program	Implement conservation with adaptive management	All regions	Improves our knowledge base, allowing future conservation management to be better targeted	$5–10m/year	High
Slowing cane toad invasion	Biocontrol, physical control, education and re-introductions	Invasion front from Northern Territory, through VB and OVP	All species that feed on amphibians, particularly predatory marsupials, freshwater crocs, large elapids, monitors	$2–5m/year	Low

* BIOREGION ABBREVIATIONS USED: NORTH KIMBERLEY (NK), CENTRAL KIMBERLEY (CK), DAMPIERLAND (DL), VICTORIA BONAPARTE (VB), ORD VICTORIA PLAIN (OVP)

Action	Activities required	Tenures, regions, locations*	Benefits to wildlife	Costs	Feasibility of actions
Slow down honey bee invasion	Fumigating hives in hollows	Invasion occurring from Kununurra where European bees are used for agricultural pollination	All hollow dependent species (although some species won't nest in fumigated hollows)	Fairly inexpensive	Moderate
Protect water for biodiversity	Research program on the effects of water extraction on biodiversity + campaigning, link with TRaCK research program	All regions	All species, water dependent	$2m or more	Moderate
Protect sawfish and barramundi	Remove barrage or create fishway on the Fitzroy	Fitzroy River, DL and CK	Barramundi, sawfish and other aquatic species	Approx. $2m (also possible culverts at Myroodah crossing $350,000–550,000) (Kirby *et al.* 2009)	High (currently being planned)
Reduce Lyngbya	Research and mitigation of nutrient sources – Roebuck Bay	Coastal areas	Coastal species	Not identified	
Monitoring diseases	Disease monitoring, dieback of trees (Centre for Tree Health)	All regions	Arboreal species		
Minimise the negative impacts of development (e.g. mining, agriculture, tourism expansion)	Advocate policies and education that promote ecologically sustainable, ethical and regulated resource extraction and development	All regions	Unspecified		

* BIOREGION ABBREVIATIONS USED: NORTH KIMBERLEY (NK), CENTRAL KIMBERLEY (CK), DAMPIERLAND (DL), VICTORIA BONAPARTE (VB), ORD VICTORIA PLAIN (OVP)

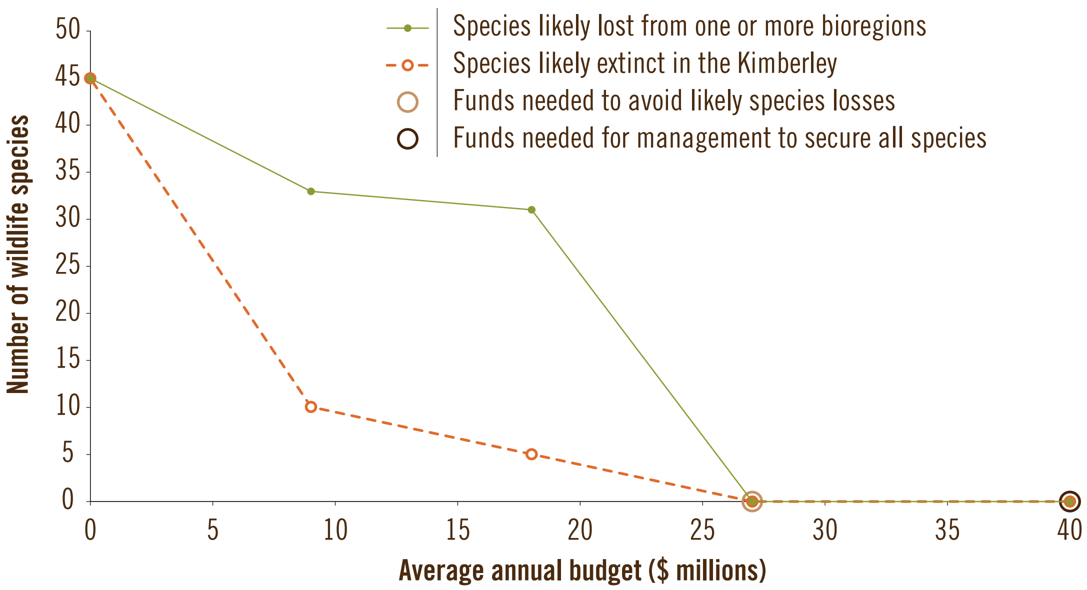


FIGURE 3
The number of species of vertebrate wildlife that are predicted to suffer loss within at least one bioregion, and from the entire region, at various levels of optimal investment in conservation management in the Kimberley and the funds required to have a high probability of securing all species.

Actions required to avoid species losses and secure wildlife

The funds available for expenditure on conservation management in the Kimberley will have a direct impact on the numbers of species that are able to be secured and the number that are likely to be extirpated from one or all of the bioregions in which they occur (*Figure 3*). If no effective management occurs, 45 species are likely to be lost from the entire region over the next 20 years. The predominant species at risk are small and medium sized ground dwelling mammals such as the Golden-backed Tree-rat *Mesembriomys macrurus* and Golden Bandicoot *Isoodon auratus*, Monjon Rock Wallaby *Petrogale burbidge*, seed eating birds such as the Partridge Pigeon *Geophaps smithii blaauwi*, Gouldian Finch *Erythrura gouldiae* and Star Finch *Neochmia ruficauda*, and a number of carnivorous reptiles, including the Spotted Tree Monitor *Varanus scalaris* and the Rough-scaled Python *Morelia carinata*. For species that are endemic to the region or are suffering range contractions in other areas (for instance Golden Bandicoot *Isoodon auratus*, Golden-backed Tree-rat *Mesembriomys macrurus*, Monjon Rock Wallaby *Petrogale burbidge* and Scaly-tailed Possum *Wyulda squamicaudata*) these would be global extinctions.

Current conservation management activities cost in the order of $20 million per year. However, much of these funds are spent on projects not solely designed to conserve wildlife and some is spent on islands, which are outside the scope of this study. Further, there has been no evaluation of whether this investment is effective at conserving wildlife. Resources are also inadequate and some are limited to discrete grant periods rather than being part of secure long term commitments, which limits the effectiveness of efforts. Even if existing funds were secure and spent optimally on wildlife conservation on the Kimberley mainland, they represent only half of the management funds required to secure many wildlife species (without considering other enabling actions such as creation of protected areas). Increased commitment to consolidating those programs that are effectively addressing the key threats identified to these vulnerable species can be achieved by the provision of additional resources to program coordination and by securing funding over the long-term.

If funds could be spent optimally on wildlife conservation, our analysis suggest that the first $9 million/year would buy a comprehensive program for controlling introduced predators across the Kimberley, as well as a fire and herbivore management program in North Kimberley (*Table 4*). This investment reduces the number of wildlife species likely to be lost from the region to approximately 10 species. However, a high number of wildlife species, 33, is likely to be lost from one or more of the bioregions in which these species occur. Doubling investment to $18 million annually, would add the implementation of fire and herbivore management in Central Kimberley and Victoria Bonaparte, resulting in a further reduction in risk to many vulnerable species including the Red Cheeked Dunnart *Sminthopsis virginiae*, Brushtail Possum *Trichosurus vulpecula*, Star Finch *Neochmia ruficauda* and Pictorella Mannikin *Heteromunia pectoralis*.

At an investment level of $27 million, we can improve the persistence probabilities of all species to at least 50%, by implementing fire and herbivore management in all regions, as well as predator control in three key regions: North Kimberley, Central Kimberley and Victoria Bonaparte. At this investment level, we are likely to avoid imminent species losses in the next 20 years (*Figure 3*, *Table 4*). However, some risks of ongoing declines would still be present: probabilities of persistence for many species are only just greater than 50% and there are uncertainties around these predicted persistence estimates.

In order to achieve probabilities of persistence of species at more secure levels (to at least 90%) across their range, the management of fire, herbivores, weeds and predators is required over all regions of the Kimberley, as well as the addition of two cat proof exclosures as insurance against introduced predators (particularly because cat control over broader landscapes currently has a low feasibility), all implemented within a monitoring and adaptive management program to measure and improve the effectiveness of the management actions. This suite of actions and their monitoring costs approximately $40 million per year[3] over the region; more in

3 All costs represent present value and would need adjustment each year with inflation

Table 4: Optimal management actions funded at various investment levels and the proportion spent on the actions in each bioregion (assuming actions are either fully funded or not funded across regions).

Average annual expenditure (set-up cost in year one)	Actions	Average annual allocation to each action	Proportional allocation to each bioregion (%)				
			NK	CK	DL	VB	OVP
$9 million ($24 million)	Fire & herbivores	$ 6.0m	67.8%	–	–	–	–
	Weeds	–	–	–	–	–	–
	Predators	$ 2.8m	3.8%	8.1%	9.5%	2.9%	7.8%
$18 million ($46 million)	Fire & herbivores	$14.6m	34.4%	36.7%	–	12.6%	–
	Weeds	–	–	–	–	–	–
	Predators	$ 2.8m	1.9%	4.1%	4.8%	1.5%	4.0%
$27 million ($72 million)	Fire & herbivores	$25.3m	23.2%	24.7%	24.7%	8.5%	16.6%
	Weeds	–	–	–	–	–	–
	Predators	$ 0.6m	1.3%	3.3%	–	1.0%	–
$40 million ($95 million)	Fire & herbivores	$25.3m	15.2%	16.2%	16.2%	5.6%	10.9%
	Weeds	$ 2.8m	0.9%	0.9%	1.6%	1.5%	2.0%
	Predators	$ 2.8m	0.8%	1.8%	2.1%	0.7%	1.8%
	Exclosures	$ 3.5m	4.4%	4.4%	–	–	–
	Monitoring	$ 5.0m	2.5%	2.5%	2.5%	2.5%	2.5%

BIOREGION ABBREVIATIONS USED: NORTH KIMBERLEY (NK), CENTRAL KIMBERLEY (CK), DAMPIERLAND (DL), VICTORIA BONAPARTE (VB), ORD VICTORIA PLAIN (OVP).

the first year to establish and build on existing programs (approximately $95 million). Additional funds would be required for any other activities deemed necessary, such as creating conservation areas. We acknowledge that it may be difficult to carry out conservation actions across entire regions; conserving wildlife in parts of regions should still be considered worthwhile.

The suite of actions highlighted above is likely to secure the 45 most sensitive species. They will benefit all wildlife to some extent, including species that are not currently on this most vulnerable list, but which are declining or have the potential to decline in the future. For example some predatory birds and reptiles with persistence probabilities of 50–80% over 20 years under a no management scenario may have higher chances of decline in the future following reductions in their prey numbers as a result of cat predation. Many graminivorous birds and wetland dependant amphibians are also vulnerable, but have persistence probabilities of only just greater than 50%. Degradation in habitat quality and resource availability for these species can be avoided with the actions we suggest, giving potentially vulnerable species a better chance of avoiding future declines.

Other benefits of conservation management actions

Conservation management actions in the Kimberley have the potential to contribute to a range of benefits other than our metric of improved wildlife persistence. Other important objectives in the Kimberley include the conservation of plants, invertebrates and vegetation communities, the achievement of more sustainable pastoral production for pastoralists, more sustainable tourism industries, improved carbon sequestration, and of conservation and land management goals as defined by Indigenous people (these may diverge from those we use due to different knowledge and value systems, many of which may be location specific) (Hill *et al.* 2005).

The success of conservation actions in achieving biodiversity and other benefits will depend on appropriate negotiations and partnerships (Smyth *et al.* 2004), especially to integrate priorities identified by other land user groups. In particular, Indigenous Australians and pastoralists play a key role in contemporary conservation management across northern Australia (Franklin *et al.* 2008) and further conservation efforts in the Kimberley should be channelled to increase support for and recognition of their involvement. Supporting Indigenous involvement in managing country is also likely to generate health benefits to Indigenous communities (Garnett *et al.* 2009).

The delivery of all actions should be strategic to maximise benefits that are identified as important during the planning processes. Note that in some cases certain actions may not be appropriate and in many cases they may require supplementation with other actions. Some examples of the benefits generated by each key action are provided below.

Fire management is likely to result in a net reduction in carbon dioxide emissions on a landscape-wide basis. This may increase commitment to this task as well as providing an extra source of funds and could also create livelihood options for Traditional Owners and pastoralists. The West Arnhem Land Fire Abatement project (WALFA) is a model for securing greenhouse gas abatement payments for prescribed burning that reduces emissions from wildfire. While climate change mitigation objectives are likely to be broadly compatible with fire management for biodiversity, at a fine scale

Fire management provides an opportunity for Traditional Owners to remain on country and transfer knowledge of traditional practices.
PHOTO: RICHARD KINGSWOOD/ AUSTRALIAN WILDLIFE CONSERVANCY

there may be some trade-offs. Fire management on pastoral land leads to decreased risks of pasture loss due to uncontrolled fire. Further, fire management can decrease the spread of weeds like buffel, Gamba and grader grass and will also improve conservation of plants throughout the region.

Introduced herbivore management creates employment opportunities in feral stock control as well as in active management of herds. Other benefits include increased landscape function with native plant conservation, improved soil health, reduced disturbance and associated weed invasions, increased availability of bush foods and improved water quality. There are also potential increases in carbon sequestration and storage, which may generate funds through future carbon markets. The removal of cattle leads to emission reductions of 1.3 tonnes per animal per year, which could amount to approximately $20 per animal per year depending on the price of carbon and likely carbon sequestration benefits from changes to soil chemistry and vegetation structure. The removal of feral herbivores may increase pastoral productivity for domestic stock and reduce disease risk. For example, the removal of pigs reduces the chances of tuberculosis outbreaks, which can cost millions of dollars.

Weed management is likely to have positive effects on the persistence of native plants, soil health, water quality and fire intensities by reducing fuel. Weed management has positive effects on pastoral productivity. The actions identified for weed management would also create jobs and livelihood opportunities, including at least five full-time positions and support for Indigenous ranger programs. In addition, early detection of weeds is likely to be important for avoiding the potentially enormous costs of eradicating problematic weeds in the future.

The Mulga Snake *Pseudechis australis* is one of the predators at risk of decline in response to decreases in numbers of the small mammals and reptiles they prey upon.
PHOTO: RAY LLOYD

Introduced predator control in the Kimberley would also create at least one full time position as well as funds for full time researchers. The research findings would be beneficial in assisting with cat management in other regions of Australia.

All of the actions have significant economic implications for the burgeoning tourism industry of the Kimberley, as one of the primary appeals of the region is the relative intactness of its species and ecosystems. Ongoing education of visitors could serve to increase the value placed on native species and healthy intact systems.

Pentecost River.
PHOTO: ROBIN CHAPPLE

IMPLICATIONS FOR DECISION MAKING

Using the information in this report

The information provided here can be used to guide investment for conserving wildlife in the Kimberley. We do not present a final prioritisation of conservation actions for the region. Cost-effectiveness depends on the objectives used; in our case the improved persistence of wildlife. When other factors are considered, the priorities may change and some actions may not be appropriate in certain locations. While we identify some of the practical considerations to be made in planning management activities (*Appendix 4* on page 64), we do not aim to address the cultural, socio-economic or spatial components necessary for an implementation plan. Neither does this report consider the effectiveness of current or future management delivery models, although this is a crucial component of successful conservation management. Rather, we present the costs of maintaining functional populations of Kimberley wildlife by abating a key set of terrestrial threats through land management actions. This information may provide a useful resource for a variety of purposes; for future planning, prioritisation and in securing increased funds for biodiversity conservation in the Kimberley.

Some of the necessary funds for conserving wildlife already exist as part of current projects, although in many cases their funding is not secure and, as we have shown here, is inadequate to prevent the loss of many wildlife species from the region. Nevertheless, future conservation activities should build upon and enhance effective existing initiatives, both for reasons of economic efficiency and to ensure that the invaluable knowledge and experience held by existing managers and decision makers is not lost. The cost-effectiveness of actions for achieving wildlife and other benefits will vary depending upon the values of the planner and implementing agent and other objectives for the region.

The additional resources we suggest do not include expenses such as the financial and opportunity costs of changing land tenure to protected areas. There have been recent commitments to expanding the protected area network in the Kimberley (Government of Western Australia 2010), which have the potential to increase the feasibility of implementing many key management actions, such as the control of introduced herbivores. The Pastoral Lands Board is currently reviewing the conditions and obligations associated with pastoral leases. Indigenous Protected Areas could play an increasing role in securing areas for conservation and enabling suitable management as well as involving the skills and knowledge of Traditional Owners. Regardless of how much of the Kimberley is dedicated to protected areas, effective management both within and outside these areas is essential. Declines in species recorded in the many existing protected areas across northern Australia indicate the importance of management across protected area boundaries (Woinarski *et al.* 2010; Woinarski *et al.* 2011).

The Chattering Rock Frog *Litoria staccato*, a Kimberley endemic, was only discovered in 2007.
PHOTO: PAUL DOUGHTY

Caveats and future directions

It was necessary to make a range of assumptions and generalisations for this analysis. These include:

- The limited information on the extent of each ecosystem type within each bioregion, as well as information on wildlife populations within each ecosystem type, meant our analysis was carried out at a coarse resolution of bioregions.
- Most of the data used in this analysis are based on the knowledge of experts which may or may not include beliefs formed on the basis of published, peer-reviewed scientific research.
- Persistence estimates of the ecological groups were averaged, which means they were assumed to respond similarly to management and disturbance, although exceptions to the group average were noted.
- For many of the conservation actions, costs were uncertain and real costs may prove to be higher or lower than predicted.
- The 'no action' scenario is theoretical as there is management currently occurring in some of the actions we identify and additional actions may be planned.
- The cost-effectiveness ranks of actions do not consider the species that are benefited by the actions ranked above them. This enabled each action to be given an independent rank. However, in reality an action that conserves a species that has not yet been conserved, is more cost-effective than an action which conserves a species that has already been protected in another region, all else being equal.

The Northern Knob-tailed Gecko *Nephrurus sheai* shelters in rocks and debris during the day, and emerges to forage at night.
PHOTO: TARA MARTIN

- Interactions between threats could not be comprehensively addressed, although they were considered to some extent.
- We assumed actions could be funded or not-funded, but in reality actions may be partially funded and there may be relationships between cost-effectiveness and increased funds to up-scale management intervention (as more funds are put into an action, the probability of success and likely benefits of the action may also increase, which may change the cost-effectiveness ranking).
- There are many uncertainties in future conditions for undertaking conservation actions in the Kimberley, such as the consequences of climate change and future developments not considered in this analysis, which would likely compound the existing threats and accelerate declines. A precautionary approach suggests that we should increase investment early, monitor and review the effectiveness of actions and be aware of emerging threats.

Our analysis is likely to be robust in terms of the relative cost-effectiveness for wildlife of the actions and the relative benefits (in terms of wildlife species losses avoided) of carrying out combinations of actions. Our method is explicit, systematic, knowledge-based, and can be updated as improved information on the costs of benefits of conservation actions becomes available. Our message explains the likely wildlife losses faced in the Kimberley without targeted increases in investment in conservation management of the region and details the best actions for avoiding these losses.

There is a great deal of additional work that would assist effective and responsive conservation management of the Kimberley region. However, it will take substantial amounts of time to complete tasks such as a comprehensive biodiversity survey and scientific study of the responses of species to threats and actions. Rapid implementation of any undisputed and 'no regret' conservation actions in the meantime is necessary to avoid imminent declines. Since uncertainty usually exists about appropriate actions (e.g. feral cat control techniques), an adaptive management framework is essential. This is a 'learning whilst doing' approach, where actions are monitored and strategically altered based on the uncertainty that is reduced as the system becomes better understood (McDonald-Madden *et al*. 2010a,b). Working with a variety of landholders will be necessary to achieve conservation management objectives. A well coordinated implementation strategy will also increase the likelihood of producing broader benefits and opportunities arising from carrying out the various conservation actions. Finally, the actions must be effective, otherwise the probability of success will decrease, the costs of delivery will increase, or both.

Some areas of additional work that we recommend are:

- Support ongoing negotiation processes with major landholder groups, particularly Traditional Owners and pastoralists, about their conservation and land management goals.
- Consideration of other taxa, vegetation communities and ecological and evolutionary processes. Plants and invertebrates including the many endemic land snails and earthworms are likely to be at least as vulnerable as wildlife due to their low mobility, high levels of endemism and small ranges.
- Further effort to identify key actions and benefits for freshwater systems.
- Further effort to identify the scale of future potential threats and how to minimise these (e.g. agricultural expansion, mining).
- Integration of this work with the trans-boundary issues of the coastal systems, specifically the inshore marine waters, islands/coastlines with associated intertidal habitats, and the freshwater inputs, as well as with marine conservation priorities.
- Integration of this work with cultural and socio-economic considerations. This step will be a critical component of successful conservation in the Kimberley.
- Research to determine the more effective and efficient delivery models for each management action.
- Designing an implementation strategy in collaboration with stakeholders.
- Developing an adaptive management framework to inform data collection and evaluate management actions.

Floodplain wetland of the Hann River as it leaves the Phillips Range, Marion Downs Wildlife Sanctuary. The impact of introduced herbivores on native wildlife are closely monitored here.
PHOTO: WAYNE LAWLER/ AUSTRALIAN WILDLIFE CONSERVANCY

CONCLUDING REMARKS

Australia has the worst extinction record for mammals of all countries in the world (Johnson 2007), and has international obligations (Convention on Biological Diversity 2006) and national commitments (Commonwealth of Australia 1999) to avoid species extinctions. Meeting these obligations will require effective and ongoing conservation management. The Kimberley is a national priority in this effort to avoid further extinctions due to its intact suite of wildlife species, including many endemics, and its role as a refuge for an increasing list of species that are declining or have been lost in other areas of northern Australia.

Many individuals and groups are working hard to plan or carry out management to help conserve the region's living landscapes and these efforts are supported by governments, non-government organisations and goodwill. However, these dedicated efforts are not currently carried out at a scale sufficient to prevent functional losses of wildlife across landscapes. Nor is their effectiveness being consistently measured or evaluated. Expansion of the Kimberley's protected area network will improve the potential for implementing conservation management, but without a substantial increase in strategically allocated funds for managing these areas, they are unlikely to achieve their biodiversity conservation goals. Experts predict a rapid decline in wildlife species in the Kimberley in the absence of additional effort. The vulnerable wildlife species are just the 'tip of the iceberg' with respect to biodiversity loss. For each iconic wildlife species there are likely to be many invertebrates, plants and other less well studied taxa that may similarly suffer declines and extinction in the coming decades.

According to our analysis, the most cost-effective priority action for protecting wildlife is the management of predation by cats (to be achieved by ceasing dingo baiting), followed by fire and introduced herbivore management. The investment in management needed to prevent extinctions of species from the Kimberley (i.e. persistence likelihood above 90% in all bioregions) is approximately $40 million per year, primarily spent on managing broadscale threats of fire, herbivore and weed management and introduced predator control. This figure also includes funds to establish and maintain two cat-proof exclosures and to implement actions as part of an appropriate adaptive management program. Additional funds and efforts are required to support planning and partnerships with landholders, including Traditional Owners, to ensure that conservation efforts are effective, efficient and socially and culturally appropriate, and to plan and coordinate implementation amongst the many agencies and landholders across the region whilst considering broader priorities and perspectives. Activities that may improve prospects for conservation management, such as increasing the area under conservation tenure and advocating new policies, would also require additional funds, some of which have already been allocated.

The science we present is designed to support decision makers. We provide key information on likely wildlife declines under various management scenarios and a prioritisation framework that can be updated to consider broader objectives. Understanding and rationally integrating information on the costs, benefits and feasibility of management actions is essential for cost-effective and defensible decision making. The actions we recommend represent an investment of less than $1 million per species saved from likely functional loss from the region and can generate other benefits such as improved employment opportunities and ecosystem services such as carbon sequestration. There now exists an exceptional opportunity to support and expand upon the efforts of the many landholders and managers who are working to build sustainable economies and conserve the rich natural values of the Kimberley.

Sand patterns at James Price Point, Dampier Peninsula. PHOTO: GLENN WALKER

The Crimson Finch *Neochmia phaeton* is an example of a riparian specialist in the Kimberley.
PHOTO: GLENN WALKER

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The Red-backed Fairy-wren *Malurus melanocephalus* is primarily an insectivore, inhabiting the non-rugged savanna of the Kimberley. PHOTO: STEVE MURPHY/ AUSTRALIAN WILDLIFE CONSERVANCY

APPENDICES

Appendix 1: Methodological details

EXPERT ELICITATION APPROACH

Expert workshops, as well as follow-up conversations by email and telephone, were used to help overcome the lack of formal data available on faunal ecology and management outcomes in the Kimberley region. The two workshops were supported by facilitators and relevant maps were readily available to assist discussion. Invitees to the first workshop were chosen particularly for their experience in field-based ecological survey of the region, giving them an understanding of faunal distribution and ecology and ecological processes determining species persistence. Contributors to the second workshop were invited for their expertise in on-ground management within the region. In particular, expertise in management of fire, grazing, weeds and feral animals was sought.

Many of the methodological details were established by the workshop contributors, especially those in the first workshop. Participants at the workshops, as well as people who contributed information but did not attend the workshops are listed in the Acknowledgements on page 1.

Eliciting information from experts is a challenging task (Kuhnert *et al.* 2010). During each of the two workshops, the elicitation was led by a facilitator and responses captured by two individuals scribing. The elicitation was conducted as a group whereby the facilitator asked questions and each workshop member provided their respective response to the group along with any reasoning, after which, the group as a whole discussed the responses and eventually came to consensus. In some cases, we wished to capture the uncertainty around responses and asked for a best and worst case scenario along with the agreed response. Although we did not formally use this uncertainty in the analysis it allowed us to understand where the information gaps were greatest.

STUDY PARAMETERS

Compilation of species lists

The lists of vertebrate wildlife species in each of the 21 ecological groups was compiled with reference to experts and published field guides (Friend *et al.* 1991; Johnstone and Burbidge 1991; McKenzie *et al.* 1991a; Hussey *et al.* 1997; Menkhorst and Knight 2002; Barrett *et al.* 2003; Wilson and Swan 2003; Pizzey and Knight 2007; Tyler and Doughty 2009). The freshwater species list includes species that spend their lives entirely within freshwater as well as species that can spend the majority of their lives within fresh water but require access to estuarine/marine areas to complete their life cycle (for example, the Barramundi *Lates calcarifer*). However, it does not consider species considered primarily of marine origin. The species list excludes all elasmobranchs (sharks and rays). In total, 637 wildlife species were considered.

Consideration of species persistence

The participants decided that the benefits of actions for wildlife would be estimated by the improvement in the likelihood of persistence of species in each ecological group if the action was carried out, compared to the case if it was not (*Table A1 on page 54*). We defined 'likelihood of persistence' as the likelihood that the species would exist over twenty years at high enough levels to perform its ecological function. The likelihood of persistence of the ecological groups over twenty years was estimated assuming that the action was implemented without further delay. These judgements were made also assuming that other threats were held constant; i.e. still impacting if present, and noting the difficulty in appraising the likelihood of damage by as

yet unrealised threats. In some cases, individual responses of selected species given as examples were noted. If species occurred across two groups, the most pessimistic of the persistence estimates was taken in the analysis so as to avoid double counting.

The Northern Brown Bandicoot *Isoodon macrourus* is a predominantly insectivorous mammal which prefers riparian and rainforest habitat.
PHOTO: SARAH LEGGE/ AUSTRALIAN WILDLIFE CONSERVANCY

Table A1: An example of persistence for some species groups under no management and with the addition of fire and herbivore management, in North Kimberley.

Bioregion: North Kimberley			Average probability of persistence with ecological function for each ecological group over 20 years		Benefits of fire and herbivore management[4]
Ecosystem	Ecological group	Examples	No action	Fire & herbivores	
Savanna (non-rugged)	Hollow/tree structure dependant – non-volant	Phascogale, Rabbit-rat, tree rats (Golden-backed, Black-footed)	0	0.45	0.45
	Hollow/tree structure dependant – volant	Yellow-bellied Sheath-tailed Bat, cockatoos, owls	0.9	1	0.1
	Ground (surface and burrowing) dwelling – 'critical weight range' mammals	Quolls, bandicoots (golden, brindled), rodents (pale field rats, Western Chestnut Mouse)	0	0.45	0.45
	Ground (surface and burrowing) dwelling – others	Diurnal skinks, Partridge Pigeon, quail, thick-knees, Cisticola	0.8	0.95	0.15
	Litter dwelling	Lizards (specialist skinks, geckos)	0.9	0.95	0.05
	Granivores	Finches (Gouldian Finch), pigeons, small rodents	0.7	0.95	0.25
	Insectivores	Small dasyrurids, thick-heads, Cisticola, ibis, fairy-wrens	0.6	0.9	0.3
	Frugivores	Emus, bowerbirds	0.6	0.9	0.3
	Nectarivores	Honeyeaters and lorikeets	0.9	1	0.1
	Herbivores	Macropods	0.9	1	0.1
	Predators	Mulga snakes, owls, dingoes, varanids, quolls	0.6	0.8	0.2

4 The differences between these persistence probabilities were calculated to determine the benefit of carrying out each action for each ecological group.

Costs

Participants in the second workshop were asked to define the costs relevant to the suites of conservation management actions. Wherever possible, these were based on past experiences of undertaking similar actions. In some cases costs would differ according to factors such as tenure or management model. These categories were recorded separately and later used to construct ranges of likely costs. The units that were costed varied according to the management action type and available data on past management. However, in most cases these were able to be converted to dollars per hectare. While the benefits to wildlife of managing fire and grazing were considered to be inseparable, and thus considered together in the first workshop, the actions were costed separately in the second workshop.

Feasibility

Workshop participants estimated the feasibility of the actions being implemented (this differs from the likelihood of achieving wildlife benefits which is considered in the persistence estimate). The feasibility was scored as a likelihood between 0–100%, using the following scale as a guide:

CERTAIN	100%
(ALMOST) PROBABLE	85%
LIKELY	75%
FIFTY-FIFTY	50%
UNLIKELY	25%
IMPROBABLE (ALMOST)	15%
IMPOSSIBLE	0%

ANALYSIS

Calculating the cost-effectiveness of actions

Conservation management actions were evaluated by combining the information on benefits, feasibility and costs. The benefit, B_{ij}, of action i (which may be a package of management activities) in bioregion j, was defined by the difference in persistence probability of all wildlife species in the bioregion with and without implementation of that action,

$$B_{ij} = \sum_{x=14} N_x.(P_i - P_o)$$

Where:

x = the number of ecological groups
N_x = the number of species in group x
P_i = the probability of persistence under action ij
P_o = the probability of persistence under a no management scenario

The total cost now (C_{ij}) of an action that requires ongoing implementation over a number of years (t – in our case t =20 years) at a discount rate per year (r – in our case r =2%), was determined using the present value equation, which measures the present value of a series of equal payments over a number of time series:

$$C_{ij} = \frac{C_{annual} \, . \, t}{(1+r)^t}$$

The cost-effectiveness, in ecological terms, of an action-bioregion ij was then defined by:

$$CE_{ij} = \frac{B_{ij} \, . \, \Pr_{ij}}{C_{ij}}$$

Where:

$\Pr_{ij}$ = the feasibility, probability of success of the action (averaged over all actions in a package)
C_{ij} = the total cost of the action (summed over all activities in a package)

Determining the trade-off between investment and wildlife persistence

We used Marxan (Ball *et al.* 2009) to identify which actions in which bioregions are required to attain persistence probabilities for all wildlife species of at least (i) 50% and (ii) 90% (or as close as possible for species which could not reach 90%). We aimed firstly for each species to reach these thresholds in all bioregions in which it occurs, and secondly in at least one bioregion (failing to meet a 50% target in at least one bioregion was taken to indicate that the species is likely to be lost from the region).

Each action in each bioregion was treated as a single action-bioregion combination (or planning unit) available for selection in Marxan. We created a file listing each action and its cost in each bioregion (a planning unit file in Marxan), and a file which listed the persistence probability of each species if each action-bioregion combination was selected (planning unit by species file in Marxan). We assumed that the benefit to each species of doing any two actions in a single bioregion could be estimated by adding the improvements in persistence probabilities for each species gained by doing those actions separately . We linked all the individual actions within each bioregion (using a modification of the boundary file in Marxan, which is designed to link planning units that are spatially connected) and set the minimum occurrence targets in Marxan at 50% and 90%, so that the 50% and 90% thresholds were counted only if the combinations of actions selected resulted in the thresholds being reached in a single bioregion.

We determined how many species reached the minimum thresholds if no action-bioregion combinations were selected and experts were asked to refine this list. We then determined the total cost of the action-bioregion combinations required to increase species persistence to at least 50% and at least 90% for each species, first in all bioregions in which it occurs and then in a minimum of one bioregion. Next we constrained the investment to two-thirds and one-third of the amount required to meet the 50% persistence threshold ($18 million and $9 million respectively) and maximised the number species for which each of the persistence thresholds could be attained. We plotted these results to illustrate the trade-offs between wildlife persistence thresholds and investment.

Appendix 2: Pathways of threats to biodiversity

Participants in the workshops described various threat pathways as part of the process of considering persistence of the ecological groups in the face of the key threats.

Fire

Workshop participants described the change in fire regimes since pre-European times as being one of the most pervasive threats to biodiversity of the region. Some of the impacts of fire on various ecosystem structural components were described by experts as follows.

Ground level impacts:

- Possible impact on termite colonies
- Increased insolation due to reduction in cover
- Reduction in coarse woody debris
- Reduction in soil seed store
- Loss of organic A horizon and mineral horizon – interrupting nutrient cycling
- Infiltration rate reduced.

Herbaceous layer impacts:

- Favouring grass species with shorter life cycles
- Favouring annual grasses over perennials.

Midstorey:

- Changing structure of midstorey – fleshy fruited species disappearing
- Reduction of midstorey vegetative species richness.

Tree layer impacts:

- Loss of veteran stag trees with hollows (hollow-bearing trees are often highly flammable and are destroyed by fire)
- Recruitment bottleneck – woodland thinning
- Reduced flower and nectar production
- Increased susceptibility to disease and insect attack.

The impacts on wildlife can be direct such as the loss of eggs of ground nesting birds such as the Emu *Dromaius novahollandiae* to indirect, for instance, decline of the Red-backed Fairy-wren *Malurus melanocephalus* due to increased parasitism by cuckoos after fire as a result of loss of understory layer increasing the visibility of their nests.

Likewise, fire-related thinning of vegetation along watercourses affects temperature and oxygen levels in the water.

Some groups of species are disproportionately threatened by inappropriate fire management. Most invertebrates are thought to be in decline, which has led to a reduction in densities of insectivores. Granivores such as the Gouldian Finch *Erythrura gouldiae* have declined with reduced availability of spinifex *Triodia bitextura* seed, while frugivores are also thought to have reduced in density. In comparison, many nectarivorous birds are nomadic and are therefore thought to be more robust to the changes brought about by fire as they can adapt nomadic habits. In addition to the noted structural changes to vegetation, some faunal and floristic groups are particularly affected. For instance, obligate seeders are highly vulnerable, while plants from the families *Cyperaceae* and *Viscaceae* are considered likely to be locally extinct within decades. More broadly, other mistletoes may have increased abundance on remaining trees but have declined overall. This has far-reaching consequences as mistletoe fruits are keystone resources for many frugivores. There are also some species, mainly generalists, advantaged by increased fire frequency. For instance, meat ants have increased, while more specialist ant species have disappeared and Brown Quail *Coturnix ypsilophora* have been favoured with associated increase in cover of buffel grass and availability of its seeds.

The impacts of fire on Kimberley ecosystems are thus far reaching. It is clear that continuation of current fire regimes will have deleterious impacts on biodiversity. However, it is less certain to what extent the changes caused by the past decades of intense and large fires can be reversed. With fuel loads now adjusted to a two year burning cycle, ecosystems may have shifted to a new stable state. Re-creating an approximation of the former structural complexity may be a long term goal. While creating specific targets for management is made difficult by the lack of baseline information on both vegetation structure and composition, there seems broad agreement that greater heterogeneity, both horizontal and vertical, is desirable.

Interactions between fire and other threat types also complicate the situation, both for interpretation and management. Fire and grazing were considered by workshop participants to have inseparable impacts, although the relationship between the threat types is complex. For instance, interactions and their influence on rainforest patches on the Mitchell Plateau were described as follows:

- Stock and no late season fire – slightly positive effect on patch
- Stock and late dry season fire – slight negative effect on patch
- No stock and no late season fire – positive as patches expand
- No stock and late dry season fire – worst effect as no buffering (stock reduce fuel load around patch).

Cattle may also be attracted to newly burnt areas early in the dry season, so prescribed burning must be carried out carefully to minimise deleterious impacts on grazing sensitive plants and other plants of value. There are also interactions between fire and weeds. Stinking passionfruit, which smothers other vegetation, is encouraged by fire, while there are strong associations between some exotic grasses such as buffel grass and Gamba grass and intense fires.

Introduced herbivores

It has been previously noted that there is substantial overlap and interaction between the impacts and management of inappropriate fire regimes and grazing impacts in the Kimberley. The combined impacts of these two realms of threat are far-reaching, with resulting sedimentation apparent in the Ord River system and even offshore.

The provision of artificial watering points throughout pastoral areas also increases the total number of herbivores present. In dry times, feral herbivores compete for water with native wildlife, with cattle drinking a substantial 35 litres per day. Some wetlands are also dried by the pugging of mud, while stream banks are eroded. The feral stock are also thought to divert productivity from the system, reducing the resources available for other fauna such

The weed stinking passionfruit *Passiflora foetida* is encouraged by fire.
PHOTO: JOSIE CARWARDINE

as macropods, which have smaller populations in areas with many cattle. Red-tailed Black Cockatoos *Calyptorhynchus banksii* in the east Kimberley may also be suffering from reduced food availability due to grazing, as well as the loss of tree hollows. Animals that depend on particular grasses and their seed set can be vulnerable. For example, in the east Kimberley, the Partridge Pigeon *Geophaps smithii blaauwi* was lost by 1910; the loss is attributed to grazing rather than fire impacts. The loss of cover is also a problem for some species, such as the Northern Brown Bandicoot *Isoodon macrourus*; formerly found in thick grassy areas around rainforests and riparian areas, it is now gone from much of its range. Also in riparian areas, the destruction of Pandanus threatens the resident Purple-crowned Fairy-wrens *Malurus coronatus*. The most direct impacts on wildlife are the loss of nests (for example, quail), by trampling. Other less direct impacts include the loss of habitat for creatures such as planigales, crustaceans and crabs that dwell in the cracks of black soil.

Feral horses can cause serious damage to a variety of habitats if they reach high densities.
PHOTO: WAYNE LAWLER/ AUSTRALIAN WILDLIFE CONSERVANCY

In comparison with wildfire, it was considered that grazing has less impact on mature trees and does not affect all tree species. However, there are clear interactions between grazing and other threat types, for instance at rainforest margins, stock force their way in and create pathways for weeds and fire. While this damage is unlikely to cause total destruction in the 20-year timeframe considered by this project, the ecosystem is suffering a gradual decline. This may have consequences of biodiversity loss disproportionate to the area destroyed.

The impacts of pigs in the Kimberley are somewhat different from those of other feral stock. They are prevalent in the northwest and in the south, with populations strongly concentrated around riverine areas, wetlands (including mound springs), mangroves and flood plains. There are particularly large numbers of pigs around the Fitzroy River. Some of these animals have been introduced by people for hunting. The impacts of pigs on biodiversity in these ecosystems are profound, including direct consumption of flora and fauna as well as loss and degradation of habitat. Many plants are consumed in their entirety, with tubers and bulbs of plants such as water lilies dug up, causing their local loss. The pigs also eat wetland wildlife including lizards, snakes, freshwater crocodiles and turtles (as well as their eggs) and consume invertebrates. They trample vegetation and prevent regeneration, creating areas subject to high erosion by churning up the soil and exposing it to the air, causing it to dry. Further impacts include the pollution of water and dispersal of weed seeds, while other problems such as transmission of disease are also considered a risk.

Weeds

The range of environmental weeds currently in the Kimberley region presents various threats, although these are not yet as severe as in many other parts of northern Australia. They are also generally less acute than the threats imposed by fire and grazing. Many of the weed problems are also related to these other threats. One such group is introduced pasture grasses which compete with native grasses, reducing food resources for wildlife and contributing to habitat homogenisation. Another group is riparian and floodplain weeds, including rubber vine, stinking passionfruit *Passiflora foetida*, *Parkinsonia* and noogoora burr *Xanthium pungen*s. In highly visited areas such as campsites, a range of species brought by visitors may colonise, but usually establish only local populations if managed quickly.

The evidence of direct impacts on wildlife from weed infestation is not always obvious; declines can be clear but may not result in extinction. Weeds compete with native plants for light, nutrients and space and changed habitat availability. However, weed mapping has shown clear differences with tenure in the northern Kimberley, reflecting the history of land use. In some case impacts on wildlife can be clearly associated, such as the loss of Purple-crowned Fairy-wrens *Malurus coronatus* from the lower Fitzroy in the 1920s. Considering the impacts of weeds on biodiversity over the next 20 years is complicated by the likelihood of future invasions. Some identified 'sleeper species' include *Mimosa pigra*, neem *Acacia nilotica*, *Lantana camera*, *Leucaena leucocephala* and guava.

Feral predators

Feral cats prey on a range of wildlife, including small mammals, birds, reptiles and invertebrates. While there is little empirical data on overall impacts, 81 species currently listed as nationally threatened are recognised as being 'adversely affected by cats' (Department of the Environment, Water, Heritage and the Arts, 2008). There may also be some competition with quolls, although this is difficult to establish. The other likely interaction is with dingoes. It is suggested that as a dominant predator, dingoes suppress the activities of cats and kill kittens, and that cat density may be inversely proportional to dingo numbers. Sand plot data from three properties in Central Kimberley showed that cat and dingo activities are inversely correlated (Kennedy *et al.* 2011). At Wongalara Sanctuary in the Northern Territory, dingo baiting occurred on half the property while it was ceased on the other half. In the unbaited area, dingo activity increased while cats decreased. There was also an increase in small lizard populations in the unbaited area. However, evidence regarding trophic interactions between fauna remains incomplete.

There may also be interactions between cat population size, hunting efficiency and other threats such as fire, grazing and weeds. These factors all affect vegetation density and structural complexity, which can reduce the amount of shelter both for cats and their prey. It is thought that a fire-prone

Feral cats are very difficult to trap, but catching live cats and researching their behaviour is an important part of learning how to manage their impacts on native fauna.
PHOTO: GLENN WALKER

history may make an area more vulnerable to cat impacts. The control of grazing and fire impacts at Mornington Sanctuary in Central Kimberley has been sufficient to allow native mammal populations to increase in the absence of effective cat control. This suggests that predation by cats deepens the impact of inappropriate fire and grazing regimes. Cat control is a contentious subject across Australia as to many people they are a much loved pet. A reduction of cat numbers may not be supported by the community.

Foxes are currently present in low numbers as far north as Fitzroy Crossing but have traditionally not extended into tropical areas. However, their range has slightly expanded and should be monitored. They pose a threat to ground-nesting birds and turtles. Dingoes are also effective in suppressing predation by foxes. It was considered important to maintain such trophic regulation to reduce opportunities for this feral predator to adapt to a semi-tropical environment.

Cane toads

Cane toads are one of the most publicly acknowledged threats to biodiversity in northern Australia. They have spread westwards from Queensland and have now reached the eastern part of the Kimberley. Their primary impact on native wildlife is the poisoning of predators, such as snakes, goannas and quolls, although there is also some predation of and competition with small fauna. While there is little evidence of extinction caused by cane toads, they have caused localised losses of wildlife populations. Losses of fauna such as goannas can also reduce the food sources of Indigenous people living on country. The main routes of dispersal of cane toads are roads and disturbed areas.

Honey bees

Another future threat to biodiversity in the region is the spread of European honey bees. These have been introduced both for honey production and to assist pollination of crops such as pumpkins. European honey bees are likely to affect hollow-nesting birds and bats, such as Yellow-bellied Sheath-tail Bats *Saccolaimus flaviventris*. Up to 50% of the tree hollows in southern forests have already been lost to honey bees.

Resource and water extraction

Although they are relatively minor issues currently, there are a variety of industrial activities undertaken for economic gain that may damage biodiversity in the region. These include mining, large-scale intensive agriculture, surface and groundwater extraction (which may be associated with either of the previous activities) as well as water impoundment. The Kimberley region is subject to a large number of mining tenements, including proposed mining for bauxite and existing mines for precious gems. Bauxite mining is comprehensive

Merten's Water Monitor *Varanus mertensi* is one of the carnivorous reptiles that is affected by cane toad invasion by ingestion of toxins when it preys upon the toads.
PHOTO: RAY LLOYD/ AUSTRALIAN WILDLIFE CONSERVANCY

Extraction of mineral resources could impose a variety of impacts on wildlife, compounding other threats. Koolan iron mine.
PHOTO: GLENN WALKER

in its destruction of vegetation and soil. Additional impacts include the extraction of groundwater, creation of roads and increased settlement, with its associated influence on other threats such as introduction of feral animals and weeds and additional wildfire ignition sources.

One of the most seasonally limiting resources in the Kimberley region, as in many parts of Australia, is water. A range of current and proposed activities involve the disruption of natural hydrological processes. These include the expansion of the Ord River scheme. There have been widespread impacts of the first Ord scheme observable throughout the catchment. However, the picture is complicated by the positive effects associated with the creation of Ramsar wetlands at Lakes Argyle and Kununurra. The biodiversity impacts of the Camballin barrage on the Fitzroy River are well recognised and there has been strong community opposition to creation of further impoundments on that river (Morgan *et al.* 2005). Construction of a fishway is being planned to minimise disruption of fish movement by the barrage (Kirby *et al.* 2009; Scott and Keenan 2009).

The links between freshwater and marine aquatic systems and their associated vegetation communities are strong in the Kimberley, partly because of the extreme tidal influence. Regulation of nutrient flow is thus of critical importance. The relatively intact riverine forests, wetlands and mangroves lessen the load of sediment and nutrients from the catchment to nearshore (and beyond) coastal and marine

communities. Mangrove forests stabilise riparian zones, reducing erosion in response to strong tidal currents along estuaries and tidal mud flats along the coastline of the Kimberley mainland and islands (Mustoe and Edmunds 2008).

One of the least well understood modes of hydrological disturbance in the region is the extraction of groundwater (Department of Water Western Australia 2009a). It is likely that groundwater sustains many aquatic habitats through the dry season and thus is critical in maintaining refugia. A recent report on sustainable yields in northern Australia recommended that, in spite of high annual rainfall, the generally higher evapotranspiration results in a landscape that is overall water limited, with little potential for water extraction (CSIRO 2009).

Increased development and populations in the area come with additional resource needs, including that for energy. Generation of this energy also brings a range of threats to biodiversity. While renewable sources of energy are generally recommended above those reliant on fossil fuels, some of these, such as tidal power may also pose threats to ecosystems such as mangroves.

Tourism

Tourism is acknowledged as a sustainable income option in remote areas but it also comes with risks. Amongst the potential risks to biodiversity are the introduction of weeds, disruption of fire regimes, litter and pollution of water features. The disruption of cattle activity, culturally inappropriate behaviour and lack of understanding of sites important to Indigenous people has added to problems, as identified in the north Kimberley (Wunambal-Gaambera Aboriginal Corporation 2001) and along the Gibb River Road (Yu and Yu 2003). With rapidly increasing numbers of tourists in the region there is a need for education and regulatory measures to be incorporated in well communicated management plans created together with local communities.

The stunning ecosystems of the Kimberley are a major attraction for tourists but tourism can also place pressure on sensitive ecosystems and cultural sites, so it needs to be planned carefully in consultation with local people. Water lilies in the Mitchell River, Mitchell River National Park.
PHOTO: GLENN WALKER

Appendix 3: Sensitivity of cost-effectiveness ranks

To test the robustness of our cost-effectiveness rankings to errors in estimates of species benefits, costs or feasibility, we subjected each of the top five (*Table A2*) and bottom five (*Table A3*) ranked actions to decreases and increases of cost-effectiveness (by altering benefits) by 20% and 30%. This was done sequentially – each time altering the parameters of only one action and starting again from the original rankings for each new alteration. This analysis indicates that the overall recommendations are reasonably robust to error in any one of the cost, benefit or feasibility predictions.

Table A2: Sensitivity of top five ranked actions.

Management action	Bioregion	Original rank	Rank if benefit decreased by		Rank if benefit increased by	
			20%	30%	20%	30%
Fire and herbivores	Victoria Bonaparte	4	4	4	2	1
Predators	North Kimberley	2	3	5	1	1
Predators	Victoria Bonaparte	1	1	2	1	1
Fire, herbivores, weeds and predators	North Kimberley	5	8	11	5	3
Fire, herbivores, weeds and predators	Victoria Bonaparte	3	3	5	2	1

Table A3: Sensitivity of lowest five ranked actions.

Management action	Bioregion	Original rank	Rank if benefit decreased by		Rank if benefit increased by	
			20%	30%	20%	30%
Weeds	Central Kimberley	20	24	24	20	19
Weeds	Victoria Bonaparte	21	24	24	18	18
Weeds	All regions	22	24	24	19	18
Weeds	Dampierland	23	24	24	20	19
Weeds	Ord Victoria Plain	24	24	24	24	21

Appendix 4: Context for implementation of conservation actions

The expert participants at the management workshop discussed the context and important considerations (largely from a western science perspective) for the implementation of the management actions. We recognise that there are many other important contextual considerations, which may in some cases override these described below.

APPRAISED MANAGEMENT ACTIONS

Fire management

The general objectives of fire management for wildlife are to increase structural heterogeneity, both temporally and spatially; reduce patch size and total area burnt; and increase mean age of vegetation as well as the distribution of age classes. A range of activities were suggested to help achieve these objectives. The actions considered for fire management included prescribed burning both from the air and on ground; creation of fire plans in consultation with landholders; fire scar mapping and monitoring; education and fire extinguishment. There would be local differences in application of these actions, dependent on biophysical factors such as terrain and soil type as well as social considerations such as tenure type and landholder participation. Monitoring the outcomes of each of the actions is important to guide the development of strategies over time. For example, there may be a time lag between undertaking activities designed to regain former structural attributes of vegetation and these attributes occurring. Fire management activities already occurring, while in many areas not at the scale considered sufficient for addressing the overall threat to biodiversity, suggest likely effectiveness of the actions and provide a model for operational management and provide a basis for making cost estimates.

Geographical location was not thought to be the primary driver of cost differences for fire management, but different models of management (largely aligned with tenure and operator) were described as affecting current costs. In this case, costs of the fire management actions were considered separately for the EcoFire delivery model, Indigenous land, land managed by DEC (unallocated crown land and protected areas) and land managed by Fire and Emergency Services Association (FESA) (other pastoral properties). Some of the differences in costs are associated with the different types of aircraft used for aerial burning, administrative burdens, and wage differences.

Given that the traditional fire management strategies of Indigenous people were enabled by their presence across the landscape, it is important to consider how to best approach the challenges of both coarse-grained and fine-grained management. While dropping incendiary devices from the air can achieve the former aim, involvement of landholders is critical for the second. All prescribed burning also needs to be planned strategically across tenure boundaries. These fire plans may consider actions of burning, chemical treatment, slashing and grading. They should also be planned in consultation with Traditional Owners, pastoralists and other landholders. These on-ground management efforts may also provide valuable opportunities for Traditional Owners to increase their time on country while gaining paid employment and continuing the inter-generational transfer of knowledge on traditional management practices and ecosystem characteristics.

Fire management for biodiversity conservation requires both coarse-grained management actions, such as prescribed burning by dropping incendiaries from the air, as well more fine-scaled on-ground management to protect particular ecological features and create a mosaic of vegetation with different ages.
PHOTO: AUSTRALIAN WILDLIFE CONSERVANCY

There is currently little investment in extinguishment of fires. However, it could be used strategically across the region if fires are detected early.

While prescribed burning may help to reduce late dry season wildfires by decreasing fuel loads and breaking up fire fronts, attention must also be paid to ignition sources. For example, one common source of ignition is grader blade sparks. A modest investment in education of road workers and negotiation with contractors engaged by local and Western Australian governments may be effective in reducing this source of ignition. Education regarding the role of fire and its management in the region may also be beneficial for other groups, to address the current misapprehension that all fire in the Kimberley is a problem.

Fire scar monitoring has already been conducted for some of the Kimberley region. This provides a history of fire events and can also be used to evaluate effectiveness of fire management efforts, indicating the size of patches burned and total area burnt in any season.

The feasibility of fire management activities was generally considered to be quite high. Interest in past projects has varied, with some, such as EcoFire finding high pastoral and Indigenous interest in voluntary involvement in fire management activities, while other offers to create fire plans and conduct aerial burning for no cost have been met with little interest. This reflects the complex range of land tenure types and management models. Although prevention of wildfires is in the interest of pastoralists, as they can impose very large financial costs, gaining full agreement on how fire management activities are carried out (for instance, timing and spatial patterning) may be more difficult. The rugged landscapes of the northern Kimberley create a high reliance on aerial burning but there is also good potential to cover a large area. In the southern area, which is less rugged and has more pastoral properties, there would be greater possibilities of fine-scale mosaic burning but higher costs and possibly lower success of negotiating with landholders.

Existing expenditure on fire management would need to increase substantially to meet the suggested wildlife persistence outcomes. A range of actions has already been proposed in the extensive investigation into rangelands fire, with a focus on the Kimberley by the Environmental Protection Authority (2006), but much remains to be implemented.

Herbivore management

The range of management options open for controlling grazing impacts is clearly circumscribed by tenure, with pastoralism having legal, cultural and financial precedence over substantial areas. However, while grazing will necessarily continue on pastoral land, legislation requires that pastoral leases are managed in an ecologically sustainable manner. There are some measures to reduce impacts by limiting either temporal or spatial access to land. For instance, areas with black soils can be protected if stock is removed sometimes during the wet season. Some very sensitive locations such as wetlands, sand seeps and mound springs can be protected by fencing, although this is expensive and requires ongoing maintenance with frequent flooding, fire and damage by stock. There may also be cultural concerns regarding fences in some areas. It was suggested that active control of herds may be more effective than extensive fencing. Protection of riparian areas on pastoral land is particularly important due to the small amount of this ecosystem type in protected land. Maintaining this habitat quality and connectivity is critical for species such as the Purple-crowned Fairy-wren *Malurus coronatus*. The potential ecological benefits of removal of stock are shown by regeneration in the upper Ord River, where native plants have re-colonised and weeds such as rubber bush have decreased. Fire management and water access are amongst the available tools for managing stock distribution, although the management costs for artificial watering points can be prohibitive. Bigger corporations are more likely to be capable of intensive management. Also, while intensification of management in a smaller area might be one possibility, it also carries substantial ecological risk.

Over the longer term, some of the greatest gains on pastoral properties may be made by investment in landholder education, with the benefits of conservative stocking emphasised. Uptake may be low until trust by landholders is earned. Greater success may be found through demonstration sites, although these can be expensive to establish. With

Feral pigs cause extensive damage, particularly to wetland areas.
PHOTOGRAPHER UNKNOWN

direct profits of pastoralism decreasing across the region, stewardship payments may also be used to encourage participation. This has not been a major part of the Western Australian land management model previously although there are incentive payments for management of Indigenous Protected Areas. Low interest loans may also provide additional management options to pastoralists.

Reform of pastoral tenure conditions and boundaries may be a policy change possible in the longer term. While there have been some adjustments of boundaries made and areas transferred to the conservation estate in advance of the 2015 pastoral lease renewal, large scale change to conservation-focused management would require change to pastoral lease tenure or conditions, as well as land use negotiation with Traditional Owners.

On non-pastoral land the main control measure is to muster where possible and shoot unmanageable stock. Cattle identified on non-pastoral land are not officially designated as 'feral'; if they are unbranded they are assigned to the nearest station.

The Judas Donkey program operated by the Department of Agriculture and Food WA has been very successful in reducing donkey populations and is one model for future operations, but several challenges remain. There can be difficulties in securing permission from all adjoining properties and cultural considerations are also important. It is often not economic or humane to transport feral stock from remote regions, while it is difficult to transport the stock to suitable markets and abattoirs. However, shooting of stock on site raises some concerns about the wastage of food. Thus, community consultation regarding management options, as well as possibilities for greater involvement should be built into any programs.

Control of pigs can involve aerial shooting, which is most feasible in the dry season as populations congregate in smaller areas. In comparison with other feral stock control there are additional challenges, such as the animals' greater ability to hide, but there are also other techniques available, such as trapping and baiting. While baiting may conflict with dingo conservation, traps can work well in areas with high densities of pigs. For any control effort to be effective, a large proportion of the population needs to be removed. There seem to be fewer social concerns with culling of pigs than of other feral stock.

Weed management

Return on investment for management of weed species varies dramatically over time. Early action following establishment of populations can be successful in eliminating them and there are opportunity costs in waiting. For example, *Parkinsonia aculeata* is a declared Weed of National Significance, but it is considered unlikely that the species will ever be eradicated from the region due to its already secure establishment. The appropriate physical management of current weeds varies with

Mesquite was introduced to Australia as a fodder, shade and ornamental tree. It has become widely established in vast areas of arid and semi-arid Australia, and is declared a Weed of National Environmental Significance. Search and spray techniques are recommended for the control of mesquite in the Kimberley.
PHOTO: ANDREW WHITE

species and with techniques including burning, fire suppression, hand spraying, aerial spraying, biological control, cutting and hand pulling.

One of the most difficult and resource-intensive parts of weed eradication is locating all populations. For instance Gamba grass is more difficult to find than to subsequently control small populations by spraying. Follow-up is also important as some species have very long lived seed banks. Considering a weed species to be controlled too early can become a later problem.

While management of established weeds can be logistically difficult and expensive, investment in quarantine can avoid some future problems. There are several types of quarantine measures possible. The Northern Australia Quarantine Strategy (NAQS) was described as a program worth expanding. The scientists employed identify potential weed problems, survey coastal sites and invest time in engagement with and training of local Indigenous people. A direct quarantine effort would be to increase the number of checkpoints for vehicles in the east and the south, as well as increasing checks at sea ports. Expanding the scope of existing quarantine procedures to have a greater focus on ecological threats, in addition to agricultural pests could also assist. Washing down of vehicles, preferably before entering the region, may help to exclude grass seeds. It was suggested that the best point of control for trucks is at the location of loading, while unloading should also be done in a sterile area.

Most weeds in the region have been deliberately introduced. Further introductions may be reduced by a combination of education and regulation. For instance, it would be desirable for nurseries to avoid stocking species that are likely to naturalise, while with more information, landholders may be less likely to grow plants that they understand to be a weed risk. It was posed that currently there may be some complacency in the region, compared with other parts of northern Australia that have suffered extensive weed infestations. Local and Western Australian governments can also list 'declared' species that are not to be grown. Currently listing of declared species is difficult if they are not considered to have a negative impact on agricultural production. Effective education relies on officers being active across the region.

The feasibility of active weed control programs (including quarantine and education) in the region would be affected by factors such as governance and institutional arrangements. Careful consideration should be given to the institutional housing of staff and projects to achieve maximum benefit. Ranger programs can help with education, identification of weed problems (for example, around camp grounds or by other targeted surveys), mapping and organising control activities. Weed control should also be carried out in concert with other rehabilitation efforts. For instance, buffel grass may have a role in stabilising soils, thus, any control should include alternative measures to prevent erosion.

Introduced predator control (cats)

There are currently no known effective broadscale actions for controlling feral cats in the Kimberley. Cats are trap shy and rarely take poisoned baits. Those around habitation are easier to trap than those in more remote areas, which have different diets. The situation is complicated by the blurred line between domestic and feral cats. Some communities in the Kimberley reportedly keep large numbers of cats, which are also free to roam and hunt. While there are few successful techniques for trapping or baiting cats, the primary feasible action for reducing predation impacts is to cease baiting of dingoes.

The Common Planigale *Planigale maculata* is an insectivorous 'critical weight range' mammal and is likely to benefit from reduced baiting of dingoes as well as improved fire and grazing regimes, as it requires dense cover for protection from predators. PHOTO: STEVE MURPHY/ AUSTRALIAN WILDLIFE CONSERVANCY

While dingoes are also predators, they frequently take prey of a larger size, reducing overall predation on small fauna, including mammals in the 'critical weight range'. A current research program is further investigating the relationship between cats and dingoes in the region and their respective predation on other fauna. However, more work is needed to effectively establish densities of both predators. Trained dogs can be useful in this work. It would also be useful to use exclosures to test the success of re-introductions of threatened mammals.

Dingo baiting currently occurs mainly in the southern pastoral areas. This is partly prefaced by the approach of the Western Australian Government to recognise dingoes as 'unprotected native fauna' under the Wildlife Conservation Act (1950). The impact on pastoralists, should baiting cease, is not well known, but not considered likely to be high as only low losses are currently reported in annual returns filled by pastoralists. The current take-up of free baiting is also not very high. Thus, some community consultation and education may be sufficient to make feasible the cessation of widespread baiting in the future, although a government policy change to cease the program would be necessary for a comprehensive change. In cases where dingo predation on stock is considered unacceptable, alternative protection may be gained from guard dogs such as Maremmas. These may also locally suppress predation by cats.

Community education regarding the problems with feral cats may also help in containing their populations. In the past, the army has provided free sterilisation for cats and dogs in Kalumbaru. This program was run to reduce health problems, but could be extended to also address the current threats to biodiversity from semi-domesticated cats. Fishing boats from Indonesia frequently have cats on board, creating a risk for offshore islands. Additional quarantine measures could be used to address this problem.

The final option considered for the management of predation by cats across the landscape was a biological control. While this would be technically feasible and likely to have substantial benefits to wildlife, it is unlikely to be socially accepted due to the popularity of cats as pets. A substantial change in community attitude would be necessary to allow such measures to occur.

Dingoes are thought to be important regulators of predation by cats.
PHOTO: MARK MCLAREN/ AUSTRALIAN WILDLIFE CONSERVANCY

ACTIONS AND THREATS THAT WERE NOT QUANTITATIVELY ASSESSED

There are a wide range of activities either currently damaging biodiversity in the Kimberley or posing the threat of future damage. Not all of these could be assessed in detail within the current project, but there was some discussion of their impacts and possible management options.

Cat exclosures

A possible measure to protect against cat predation is the creation of feral-free areas on islands or in other exclosures. These actions are focused on immediate conservation of the species, allowing for the possibility of broader re-introduction in the future, for example, should cat populations be controlled over a wide area. Bougainville Peninsula, in North Kimberley has previously been fenced, with surveys suggesting that dingoes but not cats were present. It was considered that up to eight species at the site may be extinct in the broader landscape within 20 years without such active intervention. Such areas require intensive maintenance and there are limits on the area that can be effectively secured. However, predator control in the broader landscape is also expensive and creation of sanctuary areas is likely to be a popular measure, increasing its feasibility. Islands such as Augustus and Bigge may provide good options for creating sanctuaries as they already have good populations of otherwise threatened species. While surveillance to ensure quarantine is expensive, some aerial survey is already done by customs staff. Further water-based surveillance may also provide local employment.

Management of cane toads

There are few feasible options for containment of cane toad spread westward (The Government of Western Australia 2009; Department of the Environment 2010). Management of impacts is thus likely to focus on local protection of vulnerable biodiversity. However, there are ongoing efforts such as physical control by teams of volunteers, as well as associated education measures. Other possibilities for slowing the toads' spread include creation of physical barriers on road verges. Fencing is possible, for example, by upgrading existing cattle fences with mesh, but during floods the cane toads can swim over barriers. There has been recently reported research suggesting that encouraging predation on young toads by meat ants may reduce populations, although it is unclear how widely applicable this is (Ward-Fear *et al.* 2010). Other novel approaches include the training of native species, such as Northern Quoll *Dasyuris hallycatus* to avoid eating toads (O'Donnell *et al.* 2010). However, each new generation may need to be re-trained. An option for recovering from impacts of the cane toad front may be re-introduction of some of the affected species by translocating source populations that have persisted where toads have already passed through in Queensland. While this may not be consistent with maintenance of local genetic traits, it may help to keep populations in ecologically functional numbers and allow ongoing evolution. This re-introduction should be targeted to areas of prime suitability. Another proactive measure is to ensure the natural landscape is as intact and resilient as possible to be able to minimise the impacts of cane toads

Management of honey bees

There are few clearly feasible options for containing this threat. Fumigation of wild hives around population centres or high biodiversity areas is one option, while regulation of bee keeping in the region is another. However, the likelihood of a complete ban on bee-keeping seems low. Conditions can be put on beekeeping such as a queen screening to stop swarming. There are also risks of diseases to wild bee populations (e.g. mites/short brood disorder) which can reduce bee virulence.

Kimberley sunset.
PHOTO: JOSIE CARWARDINE

Freshwater Crocodile
Crocodylus johnstonii.
PHOTO: ROBIN CHAPPLE

Brolga ***Grus rubicunda.***
PHOTO: GLENN WALKER

Green Tree Frog
Litoria caerulea.
PHOTO: DEPARTMENT OF ENVIRONMENT AND CONSERVATION WA

Goanna ***Varanus panoptes.***
PHOTO: GLENN WALKER

Common Brushtail Possum
Trichosurus vulpecula.
PHOTO: WAYNE LAWLER/ AUSTRALIAN WILDLIFE CONSERVANCY





Northern Long-necked Turtle *Chelodina rugosa.*
PHOTO: RAY LLOYD

White-bellied Sea Eagle *Haliaeetus leucogaster.*
PHOTO: ROBIN CHAPPLE

Children's Python *Antaresia childreni.*
PHOTO: RAY LLOYD/ AUSTRALIAN WILDLIFE CONSERVANCY

Desert Tree Frog *Litoria rubella.*
PHOTO: RAY LLOYD

Long-tailed finch *Poephila acuticaudata.*
PHOTO: GLENN WALKER

BACKGROUND
Boab *Adansonia gregorii.*
PHOTO: GLENN WALKER

BACK COVER
Kimberley Rock Monitor *Varanus glauerti.*
PHOTO: RAY LLOYD/ AUSTRALIAN WILDLIFE CONSERVANCY






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