Protecting the Kimberley

A synthesis of scientific knowledge to support conservation management in the Kimberley region of Western Australia

Part A: Marine environments: R.J. Masini, C.B. Sim and C.J. Simpson

Part B: Terrestrial environments: N.L. McKenzie, A.N. Start, A.A. Burbidge, K.F. Kenneally and N.D. Burrows

May 2009

Department of
Environment and Conservation

Our environment, our future

The State Government has made a commitment to develop an integrated Kimberley Science and Conservation Strategy to ensure the region's natural and cultural values are protected as its economic potential is fulfilled.

This synthesis has been prepared by the Department of Environment and Conservation as a starting point to summarise scientific knowledge relevant to biodiversity conservation in the Kimberley region. It is acknowledged that this document is not yet a comprehensive summary, particularly in respect of research conducted by other organisations and research that is unpublished.

Further information will be added during the course of stakeholder consultation and people are welcome to forward details of scientific knowledge about the region to Kimberley.Strategy@dec.wa.gov.au.

Department of
Environment and Conservation
Our environment, our future

Front cover
Cone Bay, Yampi Peninsula, showing a tidal river with mud flats, fringing mangroves and dissected mainland sandstone.
Back cover
(top row) Comb-crested jacana, golden-backed tree rat and green tree frog.
Photos – Jiri Lochman/Lochman Transparencies
(below) The kurrajong (*Brachychiton xanthophyllus*) is a deciduous tree restricted to patches of monsoon vine thicket in the north Kimberley and is gazetted as a Priority 4 species for conservation.
Photo – Kevin Kenneally

Contents

Introduction

The Kimberley extends northwards from the red dunefields of the Great Sandy Desert to the uplands, rugged escarpments and coastal islands of the sub-humid Kimberley Plateau and east to the Northern Territory border. It has a land surface area of 424 500 square kilometres, 1.8 times the size of the state of Victoria. As well as being one of Australia's fifteen National Biodiversity Hotspots, the rich tapestry of tropical marine and terrestrial ecosystems and the great complexity and beauty of the unique landscapes are attracting increasing numbers of domestic and international tourists. The Kimberley marine environment is recognised as among the world's most pristine and ecologically diverse.

The region experiences a tropical monsoonal climate with a wet season lasting from November to March and a dry from April to October. Annual rainfall ranges from 1 500 mm in the sub-humid north-west to 350 mm in the semi-arid south. Monthly temperatures average between 25ºC and 35ºC. Landscapes are dominated by open-canopied woodland with a prominent grass layer. This savanna is punctuated by strips of riverine forest, small patches of rainforest and coastal ecosystems such as mangrove. Rivers lined with stately groves of paperbarks and pandanus rise in the vast savannas of the Kimberley Plateau. Most flow north or west, incising sandstone gorges in their descent to the mangrove-fringed estuaries of the Arafura and Timor Seas. In draining the inland margins of the Plateau, others have formed extensive alluvial plains to its south and east.

Remote does not imply pristine. From a land once occupied solely by Aboriginal people, many Kimberley landscapes are now used for resource production. Over the last century, a pastoral industry has occupied the extensive plains in the south and east Kimberley and most of the Kimberley Plateau. Parts of the alluvial plains have been irrigated for crops. The size of these ancient, often massive Kimberley landscapes can mask their fragility. The spread of cattle and major changes to fire regimes have caused the most overt change of European times; degradation of the savanna that has been accompanied by a wave of extinctions among medium-sized mammals and reduced granivorous small mammal and bird abundances. Weeds and feral donkeys have followed the cattle.

In contrast, no extinctions are known from the north-western part of the Kimberley. Sparsely settled even today, the Kimberley's north-west is so rugged and trackless that the compositional complexity of its flora and vertebrate fauna have only been fully realised during the last 40 years. Indeed, the presence of rainforests in Western Australia was not recognised until 1965. Pastoral development barely penetrated this district until the early 1960s, and feral stock were scarce in its furthermost corners until the 1980s. Riverine forest and rainforest margins have been among the first north-west Kimberley habitats degraded by stock. The rivers provided corridors by which stock have spread from leases and established feral populations; rainforests damaged by cattle were noted as early as 1976. This is important because the rainforest patches contain a very high proportion of the region's terrestrial biodiversity. The increasingly pervasive changes to Kimberley environments are being exacerbated by a variety of other introduced plant and animals, such as wild passionfruit and feral cats.

There are a number of Aboriginal groups and settlements in the Kimberley and large tracts of Aboriginal land but, historically, the Kimberley has had a low population, with most people concentrated in a few towns. Unlike pastoralism, the effects of agriculture, mining, pearling, aquaculture, tourism and fishing industries are localised, although there has been a recent expansion in nature-based tourism and proposals to build infrastructure to process gas from the Browse Basin. Increased wildfire incidence and spread of weeds normally follow the development of roads and utilities to support developments.

Contemporary land-uses include conservation purposes, both government and non-government, but the declaration of conservation lands, in itself, cannot disrupt the broadscale mechanisms degrading Kimberley ecosystems. Here, and in the two parts that follow, we present a synthesis of marine and terrestrial science to support conservation policy and management and identify knowledge gaps critical to decision making.

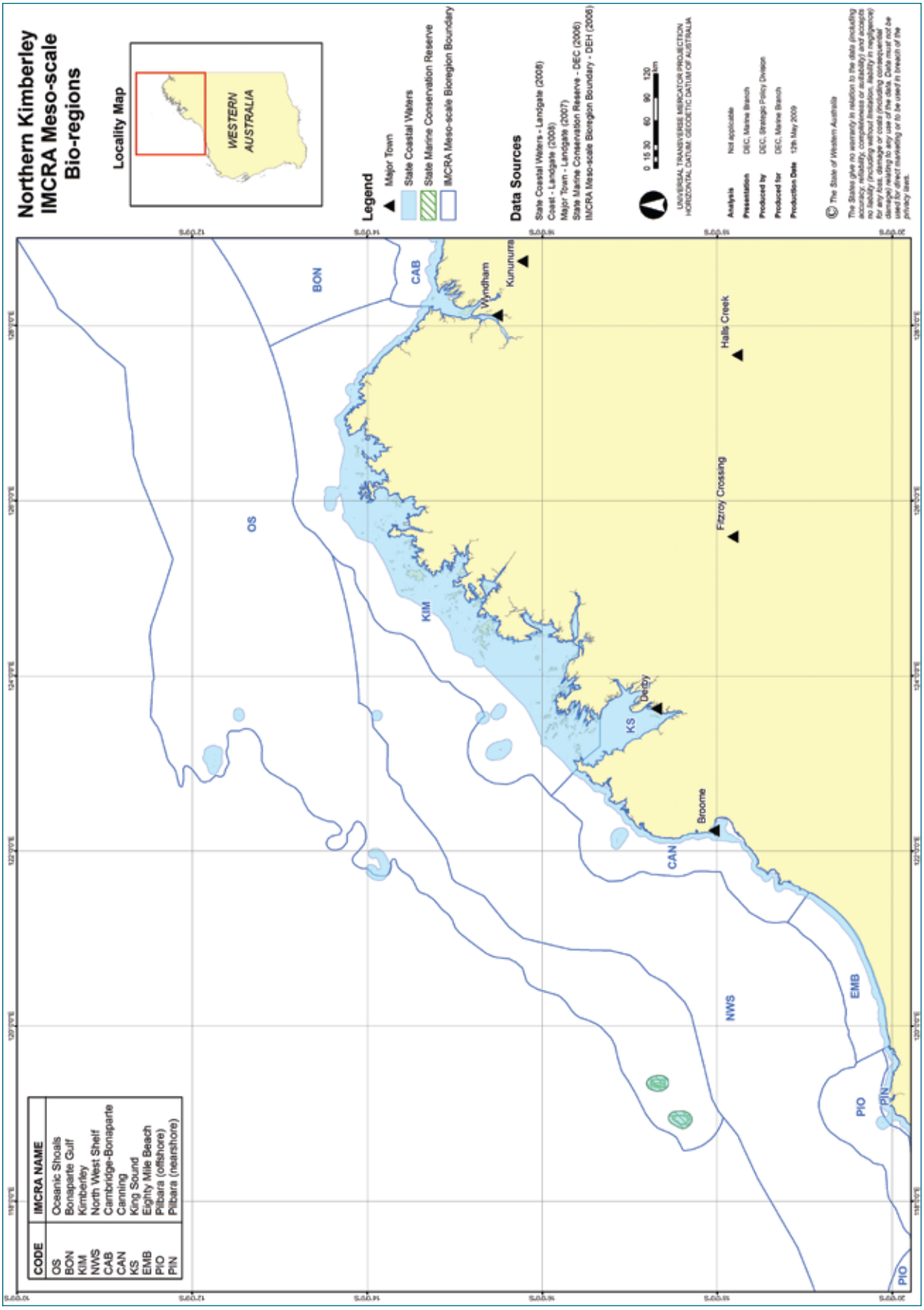
Ray Masini, Cam Sim and Chris Simpson

Overview

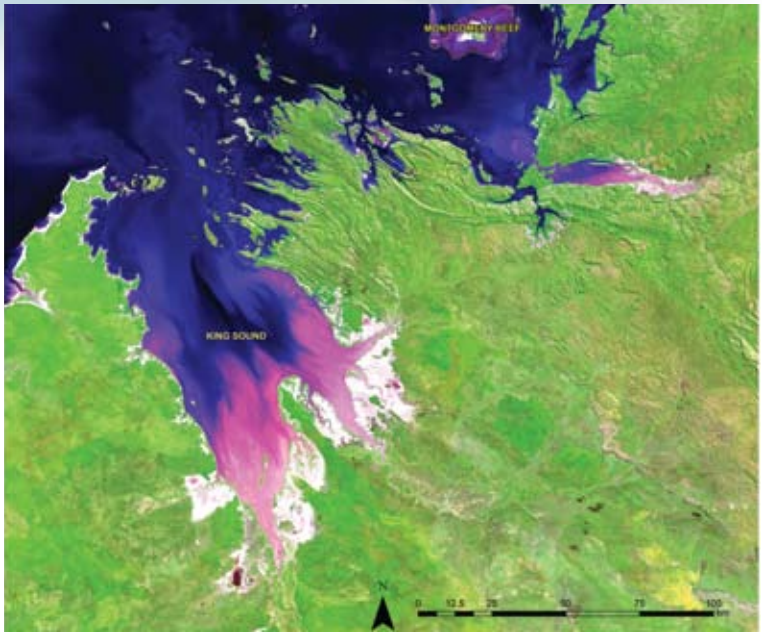
Most of the marine environment in the Kimberley region is internationally recognised as being in very good ecological condition. Halpern *et al.* (2008) in assessing the condition of the world's oceans reported that 41% of the global marine environment has been adversely impacted by humans to a "medium-high to very high" extent and only 3.7% of oceans were rated as "very low impact". Very low impact areas are restricted mainly to the high latitude Arctic and Antarctic polar regions and notably northern Australia including the Kimberley. That most of the world's other coastal tropical marine areas are degraded to varying degrees emphasises the global conservation significance of the tropical marine environment of the Kimberley. However, there are growing human usage pressures in the region that will require sound scientifically-based management if the condition of the marine environment is to be protected (Wood and Mills 2008).

While there is a growing body of scientific knowledge about the Kimberley marine environment (e.g. Fletcher and Head 2006, Department of the Environment, Water, Heritage and the Arts 2008, Holley and Prince 2008, Wood and Mills 2008), it is relatively small compared with marine areas at similar latitudes off the east coast of Australia (e.g. Great Barrier Reef) where there exists a substantial information base to support management. The limited scientific understanding of the Kimberley marine environment has largely been due to the region's remoteness and the associated high costs of conducting research. As a result, most research has been opportunistic, exploratory or descriptive in nature. Interest in recent years from the petroleum sector in exploiting hydrocarbon reserves in the Browse Basin has provided particular impetus for Government and the private sector to increase scientific understanding of key Kimberley marine systems. This information is needed to inform decision making and support delivery of regional plans and conservation outcomes. In response the WA Government has committed to develop a *Kimberley Science and Conservation Strategy* "to ensure the region's natural and cultural values are protected as the region fulfils its economic potential". In addition, the Western Australian Marine Science Institution (WAMSI) has prepared a report identifying priority marine research to address management issues facing the Kimberley (Wood and Mills 2008).

Figure 1: Interim Marine and Coastal Regionalisation of Australia (Version 4.0) meso-scale bioregions from Eighty Mile Beach to the Western Australia-Northern Territory border.



The Interim Marine and Coastal Regionalisation of Australia (IMCRA Version 4.0) recognises biogeographical boundaries that are primarily based on regional geological characteristics and history, which provide insight into regional ecological patterns. Regionalisation provides a broad-scale classification of different marine areas of the Kimberley coast (Fig. 1). Regional scale drivers of marine communities and their ecology include geological substrate and geological history, oceanographic features including temperature, salinity and ocean currents and circulation patterns (Cresswell and Badcock 2000). Local influences include substrate types, exposure to tidal currents and wave energy, and proximity to river discharges.



Above Colour enhanced satellite image showing extensive turbidity plumes in coastal waters in the King Sound area, southern Kimberley (pink to light blue colour tones). Turbidity plumes in coastal areas of the Kimberley are associated, in part with the discharge of sediment laden freshwater from rivers as well as with significant tidal variation. This image serves to illustrate connectivity between land and marine ecosystems in the Kimberley. The functional significance of terrestrial run-off for the region's marine ecology is largely unknown. Image – DEC and Commonwealth Department of Climate Change).

Ecological processes that link land and sea are also likely to be important and in this respect it is relevant to recognise relationships between terrestrial and marine regionalisation schemes. The Kimberley IMCRA region corresponds broadly to the offshore extent of the Kimberley Basin (Plateau) and North Kimberley IBRA Regions and the Canning IMCRA Region corresponds to the Canning Basin.

While identifying a number of bioregions between Eighty Mile Beach and Cape Londonderry, the IMCRA recognises two broad environments in the region, being the nearshore/coastal and offshore, each with quite different characteristics and values. For the purpose of this paper, the nearshore and offshore environments and their associated IMCRA bioregions are considered separately.

Nearshore and coastal environments (Canning, Kimberley and King Sound IMCRA Bioregions)

Key physical characteristics common to the nearshore and coastal waters of the Canning, Kimberley and King Sound IMCRA meso-scale bioregions (Fig. 1) include turbid waters, low wave energy and a macrotidal regime. Tides are semidiurnal (i.e. two high tides and two low tides each day) with daily amplitude of up to ~11 metres during spring tides and less than ~3 metres during some neap tides, meaning the region experiences some of the largest tides, and correspondingly large degree of water movement, along a coastline adjacent to an open ocean in the world.

Coastal geomorphology and bathymetry are other key influences on the region's marine ecology. The Canning coast from Cape Leveque to Cape Bossut is characterised by beaches between large deeply incised, often barred, embayments with associated lagoons and extensive tidal flats. The offshore bathymetry is gently shelving. In the Kimberley Bioregion, deep coastal valleys were inundated by the sea during past sea level rise events forming the ria type coast with its many gulfs, headlands, cliff-lined shores and archipelagos that now typify this region. There are 2 581 mapped islands between Yampi Sound and the King Edward River estuary. The straight line distance between Yampi Sound and the King Edward River is approximately 400 kilometres whereas the actual length of coastline is about 12 850 kilometres, a ratio of approximately 1:30. Extensive tidal flats have formed in places and these are sometimes associated with the mouths of the numerous rivers that drain sediment-laden freshwater to the coast in the region. Peak river flow is seasonal and generally associated with the northern monsoon. King Sound is a wide gulf with a low relief shoreline and associated intertidal and supratidal flats.

These features, and the semi-diurnal macrotidal regime, mean that the land-sea interface is large and together these features are among the primary controlling factors influencing the productivity and biodiversity of the Kimberley's nearshore marine environment.

Biologically, the nearshore and coastal environments support a diverse array of marine communities including coral reefs, seagrass meadows, mangrove forests and sponge gardens. These communities in turn provide critical habitat, shelter and food resources for specially protected and culturally and commercially important species including marine turtles, cetaceans, dugongs, fish, prawns and birds.

Offshore environments (Northwest Shelf and Oceanic Shoals IMCRA Bioregions)

In contrast to nearshore waters that are under coastal influence, environments offshore are characterised by generally clear waters that are typical of oceanic systems. There are mid-shelf islands (e.g. Browse Island), some embankments and shelf-edge atolls (e.g. south Scott Reef and Clerke and Imperieuse reefs in the Rowley Shoals group) in the bioregions that are under State jurisdiction. The waters around Adele Island are under State jurisdiction, while the island itself is a nature reserve. There are State and Commonwealth managed marine reserves at the Rowley Shoals, three coral atolls west of Broome. The geomorphology of the region's oceanic reefs and banks and offshore islands has been described in considerable detail in Berry (1986). The region's shelf-edge atolls warrant particular mention for their unique formation and structure.

Known key ecologic attributes and values

Ocean currents and circulation

Large-scale oceanography in the region is highly seasonal and a number of ocean processes influence the area. The Holloway Current for instance is a surface layer pole-ward flowing ocean current that brings water from the Banda and Arafura seas southward along the continental shelf in the region at the end of the northwest monsoon. The pole-ward flow of this and other ocean currents in the region is globally unique. Despite this, an understanding of the Holloway Current and the origin of shelf waters throughout the Northwest Marine Region is poor.

River flow to the marine environment is likely to be an important factor influencing the region's marine environment. However, evaluating this influence will depend on a much-improved understanding of the spatial and temporal characteristics of alongshore and cross-shelf water circulation and exchange. Understanding ocean currents and local-scale circulation and exchange patterns, and the influence of these, is important for evidence-based decision making in relation to Environmental Impact Assessment (EIA) of development proposals, planning for biodiversity conservation and sustainable use of marine resources.

Bathymetry

Bathymetry in some areas is well known, however, over vast areas of the region high-resolution contemporary bathymetric data are limited or not available and many areas remain uncharted. Geoscience Australia (GA) have broad-scale data for the region, though bathymetric measurements by the Australian Institute of Marine Science (AIMS) and CSIRO (Fry *et al.* 2008) during benthic habitat surveys in the southern Kimberley in July 2008 indicate that local-scale bathymetry at the survey locations varied from the GA data. The Australian Hydrographic Office (AHO) is currently processing data from contemporary surveys in the northern Kimberley.

Reliable bathymetric data are fundamental for predictive modelling of water currents and circulation patterns, which in turn are used to inform EIA and understand the degree and extent of ecological linkages between different areas (e.g. larval dispersal). Good bathymetry can also be used as a surrogate to infer habitat types for broad-scale benthic biodiversity mapping where ecological field data are limited.

Coral communities

Coral reefs are well developed in the Kimberley, Northwest Shelf and Oceanic Shoals bioregions in particular and are one of the region's most important marine values. Coral communities are not well developed in the Canning Bioregion, though there are some localised examples off the Dampier Peninsula coast and a biogenic reef structure at the Lacepede Islands (Fry *et al.* 2008, Marine Parks and Reserves Selection Working Group 1994). Development of coral communities in the King Sound Bioregion, particularly in the inner section, is limited due to persistent high water turbidity characteristic of the Sound.

Coral reefs in the region fall into two general, though distinct groups — the fringing reefs around coastal islands and the mainland shore, and large platform reefs, banks and shelf-edge atolls offshore. Cape Leveque

is an approximate demarcation point north and east of which coral communities become well developed in nearshore environments. Preliminary reconnaissance surveys by DEC (unpublished data) and other studies undertaken by the WA Museum and collaborators (Wells *et al*. 1995) and mining companies around islands in the Buccaneer Archipelago indicate that extensive fringing reefs which support high abundance and diversity of coral have developed around many islands and off some mainland shores.

Further east, work by DEC and the LNG industry indicate that fringing and emergent coral reefs are well developed in the Heyward island group, around islands in the Bonaparte Archipelago, and off mainland shores of Cape Voltaire and Cape Bougainville. Surveys by INPEX of Maret, Bethier and Montalivet islands, which were largely restricted to the intertidal zone, have recorded 280 species of coral from at least 55 genera, making the Kimberley Bioregion the most coral-diverse area in WA (INPEX 2008).

Extensive biogenic reef formations have been identified off the west coast of the Anjo Peninsula, but these reefs supported a low cover of live coral at the time they were surveyed (DEC 2008). Further offshore from the Admiralty Gulf, between Cape Voltaire and Cape Bougainville, lies Long Reef which is an emergent biogenic reef of some 150 km^2 rising out of approximately 30 metres of water depth. Long Reef has well developed live coral communities on its periphery.

The WA Museum and collaborators published results of three marine biodiversity surveys in the Kimberley between 1995 and 1997 (Walker 1997, Walker *et al*. 1996, Wells *et al.* 1995). Most survey effort was restricted to the intertidal zone. The survey reports provide accounts of reef geomorphology and include preliminary species lists for some sites visited over the three surveys. Some research has also been conducted at Montgomery Reef which is a biogenic reef of some 300 km^2, located between Camden Sound and Collier Bay.

Aerial photographs and satellite imagery indicate that fringing reef-type formations are very extensive in the Kimberley, however further analysis of the available remote sensing data coupled with targeted field verification are necessary to classify and map the different fringing reefs in the region. Preliminary analysis indicates that the Kimberley contains a fringing coral reef province that will rival the Red Sea in terms of the extent of reefs.

Top Fringing reef, Buccaneer Archipelago Photo – DEC

Above Subtidal coral reef communities are well-developed around some inner and mid-shelf islands and mainland shores. Photo – A. Heyward, Australian Institute of Marine Science

Left An extensive fringing coral reef at low tide, South Maret Island. Photo – DEC

Coral communities have been studied on shelf-edge atolls in the Oceanic Shoals Bioregion which are under WA jurisdiction. Drilling at Scott Reef has shown that geological history of shelf-edge atoll formations is unlike that of coral atolls found in the Pacific Ocean, which have mainly developed on the submerged rims of volcanos. For example, studies of drill cores from Scott Reef indicate that reef formation was initiated in the mid-Miocene period (~15 million years ago) and development has waxed and waned since, partly in response to variation in sea level. There is evidence of biogenically formed reef material approximately 2000 metres below the present sea level (Berry 1986).

A long-term research program is being undertaken by AIMS at Scott Reef, which includes investigations of the effects of tropical cyclones and elevated sea water temperatures (Smith *et al.* in prep.). A benthic habitat map of the Scott Reef system has also been produced (Smith *et al.* 2006). DEC has recently conducted research on the coral and associated communities in the reserve areas at the Rowley Shoals west of Broome (Long and Holmes 2009). These research programs show that the coral communities are diverse and in very good condition. The reefs in the Oceanic Shoals Bioregion probably play an important role as ecological 'stepping stones' that help maintain connectivity between the marine flora and fauna of the Indo-west Pacific and Australian west coast ecosystems. This requires further investigation.

Based on the scale of reef development and the diversity of coral species recorded through limited survey, it is highly likely that further survey will demonstrate that the Kimberley contains a coral reef province of global significance.

Seagrass communities

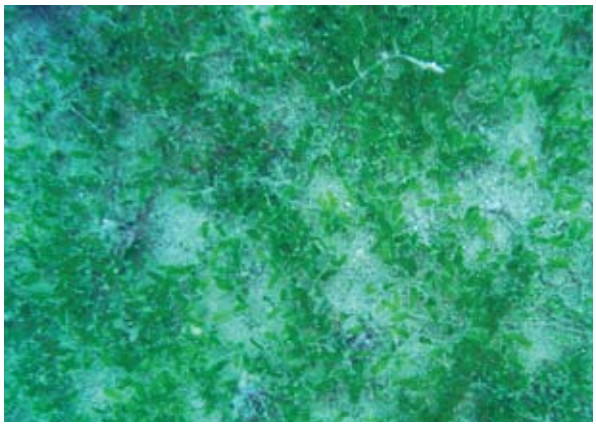
Seagrasses are biologically important for four reasons: 1) as sources of primary production, 2) as habitat for juvenile and adult fauna such as invertebrates and fish, 3) as a food resource, and 4) for their ability to attenuate water movement (waves and currents) and trap sediment.

Western Australia has the highest diversity of seagrass in the world with 25 species represented. Twelve species are known from WA's tropics, including one endemic (*Cymodocea angustata*). Nine species expected to occur in the tropics were collected from intertidal sites in the Kimberley by Walker (1995, 1996 & 1997). Extensive and diverse intertidal seagrass meadows are known from islands in the southern Kimberley, particularly around Sunday Island (Walker 1995, Walker and Prince 1987). It is likely that these meadows would be utilised by a variety of species including prawns and fish as well as specially protected and culturally important species such as turtles and dugong. While some seagrasses were collected from intertidal sites in the central and north Kimberley (Walker 1996 & 1997), these areas were not found to be as species rich and did not support extensive seagrass meadows like those found by Walker (1995) in the southern Kimberley.

Until recently, most of what is known about seagrass in the region was based on collections of individual voucher specimens from sites in the intertidal zone (Prince 1986, Walker 1995, 1996 & 1997, Walker and Prince 1987) and there was very little known about the subtidal communities.

Dugong feeding in the vicinity of James Price Point (Prince 1986) suggested the presence of seagrass in that area, but this was not verified until recent benthic habitat surveys by DEC and CSIRO/AIMS between November 2007 and December 2008. These surveys found seasonally-abundant subtidal seagrass communities patchily distributed across large areas along the Dampier Peninsula from the lower intertidal and out to a depth of approximately 20 metres. Maps showing subtidal seagrass cover and distribution have been produced from a

Below Seagrass in the Kimberley is an important food resource for dugong and turtles; **left:** Intertidal seagrass, Maret Islands; **right:** Dense subtidal *Halophila* meadow, Dampier Peninsula. Photos – DEC



single but very comprehensive dry season survey in the southern Kimberley (Fry *et al.* 2008, see Fig. 2). Subtidal seagrass patches and meadows appear to be well developed in areas where sediments were relatively fine and stable such as in inter-reefal areas and between/among patches of filter-feeder communities. These subtidal meadows were first observed during surveys undertaken by DEC in November 2007. At this time, meadows were well developed and biomass was high. Repeat surveys of some locations where seagrass was found in November 2007 were undertaken in April 2008 but no seagrass was recorded. Seagrass had re-established in these areas by June 2008 and surveys by DEC in December 2008 found prolific seed production in *Halophila* sp, suggesting that recruitment from seed may be a very important process for sustaining these seagrass communities. Community monitoring co-ordinated by the Global Seagrass-Watch program is being carried out to map seagrass communities in intertidal areas of Roebuck Bay (McKenzie 2007).

Apart from localities on the Dampier Peninsula mentioned above, there are no maps of intertidal seagrass habitats and very limited information about the extent and distribution of subtidal seagrass habitats in the region. Furthermore, little is known about the ecological role and importance of seagrass communities in the region or the key processes that sustain them.

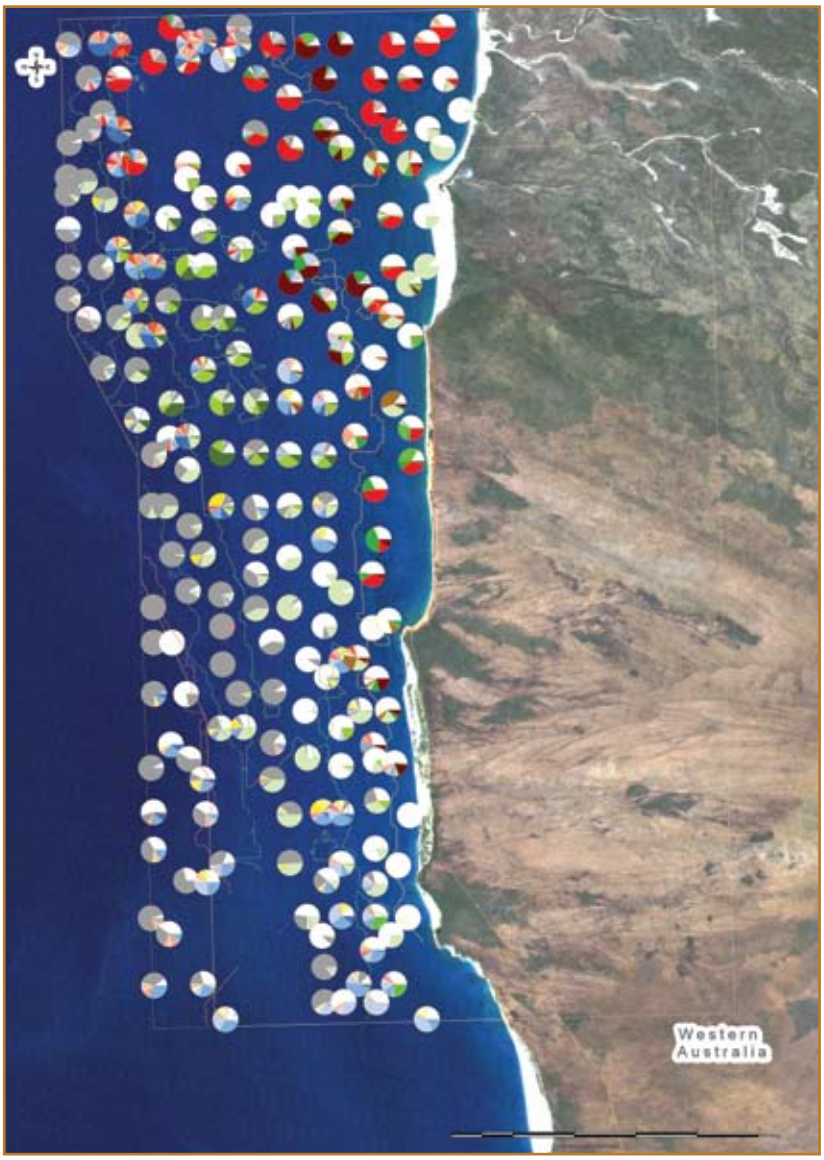


Figure 2: Pie charts showing the relative proportions of different benthic habitat types recorded during benthic habitat surveys of the area between Quondong and Coulomb Points on the Dampier Peninsula, north of Broome in June 2008. Each pie chart shows data for a 500 m long underwater video transect (source: Fry *et al.* 2008).

Data Sources

Benthic habitats – video survey conducted during June 2008 as part of a collaborative project between CSIRO Marine and Atmospheric Research, the Australian Institute of Marine Science (AIMS WA) and the Department of Environment and Conservation (WA). Funded by the Northern Development Taskforce.

Bathymetry – Contours (5, 10, 15, 17 and 20 metre) derived by AIMS based on height datum, AHO Broome Predicted (4.55m above MSL).

Imagery – Australian Greenhouse Office Landsat Mosaic 2005.

Basemap – Geoscience Australia 250K Series Version 3.

Datum – Geodetic Datum Australia 1994 (GDA94).

Legend

No Biohabitat
Bioturbated
Alcyonarian Garden Sparse
Alcyonarian Garden Medium
Alcyonarian Garden Dense
Whip Garden Sparse
Whip Garden Medium
Whip Garden Dense
Gorgonian Garden Sparse
Gorgonian Garden Medium
Gorgonian Garden Dense
Sponge Garden Sparse
Sponge Garden Medium
Sponge Garden Dense
Hard Coral Garden Sparse
Hard Coral Garden Medium
Hard Coral Garden Dense
Live Reef Corals
Algae Turf / Microphyto
Algae red / green mix
Algae Halimeda
Algae Sargassum
Algae other brown
Seagrass Sparse
Seagrass Dense
Bivalve Shell Beds

Filter-feeder communities

Filter-feeders are invertebrate animals that feed by filtering small particles from seawater, typically by passing the water over a specialized filtering structure. Examples of filter-feeders are sponges, soft and whip corals and sea squirts. Filter-feeder communities are aggregations dominated by these animals growing together on consolidated seabed and some of the most well-developed communities have been found elsewhere in WA in waters deeper than 40 metres (e.g. off Ningaloo Reef).

Recent dry season underwater video surveys by AIMS and CSIRO (Fry *et al.* 2008) indicate that filter-feeder communities are a prominent component of the subtidal benthic environment off the Dampier Peninsula and Gourdon Bay, south of Broome (Canning Bioregion) in water depths as shallow as 10 metres. These communities are patchily distributed and vary in terms of their spatial extent, diversity and cover but generally appear to be associated with stable hard substrates overlain by sand veneers in areas of gently shelving bathymetry. Abundance and species diversity appear to be high in places, however very little is known about the species represented in these communities or their ecology. A preliminary assessment by local experts indicates that many of the taxa present may be undescribed and hence likely to be new to science (J. Fromont, pers. comm.).

Surveys by DEC in the Kimberley Bioregion revealed that filter-feeder communities occur in the areas associated with fringing biogenic reefs. In these areas, filter-feeder communities tend to occur where the substratum is hard and steeply sloping, and/or where light availability is limiting for hard corals. A generally repeating pattern that has been observed around fringing coral reefs is that benthic cover gradually shifts from a predominance of hard corals to filter-feeders with increasing water depth. Preliminary observations suggest that the transition from corals to a predominance of filter feeders tends to occur at water depths of approximately 10 metres (below estimated mean sea level), which is much shallower than in other tropical areas in WA (e.g. Ningaloo Reef). Communities also appear to be well developed down steeply sloping reef fronts and in deep sandy basins and subtidal reef platforms off island and mainland shores to depths of at least 35 metres.

Below Diverse communities of filter feeding invertebrates have been observed on low-relief subtidal reef pavements in the Kimberley.
Photos – A. Heyward, Australian Institute of Marine Science

From underwater video footage collected during recent surveys in the Kimberley, there is often an abundance of small fin fishes and some large demersal fishes (e.g. snappers and gropers) associated with filter-feeder communities. This observation is supported by data from Ningaloo Reef and suggests that filter-feeder communities in the Kimberley provide important habitat for fish populations.

With the exception of work off the Dampier Peninsula, little is known about the extent and distribution of filter-feeder communities in the Kimberley and research is needed to test the broader transferability of observations about the apparent association between fringing reef and filter-feeder communities. Species composition and diversity of subtidal filter-feeder communities, and the seasonal and/or inter-annual variation in the structure of these communities in the region are unknown, as is the ecology of filter-feeder communities including the key processes that sustain them.

Intertidal systems

Very large tidal amplitudes in combination with the extensive and complex coastline produce very extensive, ecologically diverse and highly productive intertidal areas with environments ranging from vertical cliffed coasts to wide expanses of mudflats, sand banks, coral (addressed earlier) and algal reef flats, mangrove forests and beaches.

The gently shelving nearshore bathymetry of the Canning Bioregion produces areas of extensive mudflats and sand banks. Sand/mud flats may be kilometers wide in some places, providing habitat for diverse assemblages of burrowing and crawling invertebrates. Seagrasses are also often present and are a critical food resource for dugong.

The intertidal benthos has been studied at only a few locations in the region. Roebuck Bay and Eighty Mile Beach in the Canning Bioregion have received most attention. Both areas are Ramsar-listed wetlands primarily because of the seasonally high numbers of migratory birds they support (including species listed under the Japan-Australia Migratory Birds Agreement (JAMBA) and the China-Australia Migratory Birds Agreement (CAMBA)). For example, in terms of total numbers of birds utilising the area as a migratory terminus or stop-over site, Eighty Mile Beach is one of the most important non-breeding and migratory stop-over areas in the East Asian – Australasian Flyway for use by migrant shorebirds (CALM 2003). The rich intertidal invertebrate communities recorded from these locations provide an important food resource for the seasonally abundant bird populations (Piersma *et al.* 1999 & 2006). While Roebuck Bay and Eighty Mile Beach studies have identified abundant and diverse intertidal faunas, similar research has not been undertaken at other sites so it is not known whether these are typical of tidal flats across the Kimberley.

Surveys of intertidal habitats at three locations in the Canning Bioregion (Gourdon Bay, Perpendicular Head and Packer Island) have recently been undertaken for the Government's Northern Development Taskforce (WA Museum 2008). The surveys revealed the study areas to be broadly representative of the Canning Bioregion in terms of diversity and assemblages of biota, with each having examples of all or most of the habitat types present in the bioregion. The relative importance of habitats and communities varies between locations, though in the absence of broader regional studies it is not possible to make informed appraisals of the significance of individual sites. Waples (2007) notes that some research has also been conducted at other sites in the King Sound and Cambridge–Bonaparte Bioregions but the majority of intertidal studies have focussed on mangroves.

Mangrove communities are important for providing a source of nutrients to surrounding waters, for fauna habitat and as a buffer against wave action to reduce erosion and maintain coastline stability. Mangroves are very well developed in the Kimberley and from a global perspective, these mangrove ecosystems are considered to be relatively pristine (IUCN Working Group on Mangrove Ecosystems 1981) having not been subject to broad-scale deforestation and fragmentation due to coastal development. Mangrove systems also provide a nursery and breeding area for various fish stocks (Loneragan *et al.* 2002) and it is considered that these systems are important for sustaining some major fishing industries. A better understanding of the marine ecology of Kimberley's mangrove systems is warranted.

Pendretti and Paling (2000) developed a database of mangrove sites along the WA coast and made assessments, based on information available at the time, of each site against the Australian Heritage Commission's Register of National Estate Criteria. A database is available on the internet and DEC has recently refined the associated spatial data, however, there is a need to validate its accuracy and to ensure it remains current. Fine scale and accurate mapping of mangroves would provide a valuable record of mangrove areas so that changes and trends, driven by both natural (e.g. cyclones) and anthropogenic influences (e.g. oil spills, climate change effects), may be detected and assessed. In terms of species diversity, 19 of the 41 species of mangrove which occur in Australia are represented in the Kimberley but there are no species unique to the region. (E. Paling, Murdoch University, pers. comm.). From a marine ecological perspective, there are at present large gaps in basic knowledge such as mangrove habitat assemblages and their extent and distribution, soil types, faunal species including fish, and roles and contributions of exported nutrients to marine productivity.

Little is known about the ecology and biodiversity significance of rocky intertidal shores. Rapid one-off surveys have been conducted at numerous intertidal sites in the Kimberley by the WA Museum and collaborators during voyages through the region in the mid-1990's (Walker 1997, Walker *et al.* 1996, Wells *et al.* 1995). The survey reports provide accounts of intertidal invertebrate, macroalgal and seagrass diversity. Surveys of the intertidal zone have been conducted for petroleum industry proponents, but the results of these surveys are not published.

Above The Kimberley coast provides calving and resting habitat for Humpback whales. Photo – C. Jenner, Centre for Whale Research.

Whales and dolphins

A number of cetacean (whale and dolphin) species are known to occur in the Kimberley region including humpback whales, the snubfin dolphin as well as several other species of delphinid. These species are important because of their iconic status and public appeal and also for their conservation value. Humpback whales are specially protected species in WA due to their threatened status.

Information about humpback whale utilization of the region has increased considerably since the mid-1990s. The Kimberley is the northern migration destination and calving ground for the largest population of humpback whales in the world. Since cessation of whaling for humpback whales off WA's coast and in the Southern Ocean, the 'Group IV' population (i.e. the one which migrates along the WA coast to the Kimberley) has increased by 10% per annum and in 2007 was estimated to comprise some 20 000 animals. On the basis of data collected over a 10 year period, there is an important humpback whale calving and resting area between the Lacepede Islands – Beagle Bay in the south and Camden Sound in the north (Fig. 3). While some cows will calve and rest outside this area, most whales outside the area are migrating animals. The northern migration peaks in July but occurs through July to September. The southern migration peaks for cows with calves at the end of September. Other whale species observed inshore and offshore in the region include pygmy blue whales, false killer whales, pygmy killer whales and blue whales.

There are populations of snubfin dolphin, recently identified as taxonomically unique to Australia, found in coastal waters of the north (Beasley *et al.* 2005). This species has received limited attention, but a research program is currently underway by Deakin University to examine the distribution, abundance and general ecology of the species in the Kimberley. Other dolphin species known from the region include the Indo-Pacific bottlenose dolphin and Indo-Pacific humpback dolphin, striped dolphin and spinner dolphin. A number of other species may also be present. Greater survey effort would be required to confirm this.

Dugong

In Australia, dugongs occur in northern waters from Shark Bay to the Kimberley and across the top end to Torres Strait and down the Queensland coast to Moreton Bay. The dugong is an air-breathing herbivorous marine mammal that relies primarily on seagrasses for food. Its reliance on large meadows of seagrass in shallow waters close to land has resulted in a significant decline in numbers throughout much of its Indo-Pacific range as a result of human activity and natural events. The dugong is considered vulnerable under international conventions and is afforded special protection under the Wildlife Conservation Act in WA. Dugong are widely known from the region and have strong cultural significance for coastal indigenous people of the Kimberley.

Prince (1986) and Walker and Prince (1987) provide accounts of knowledge about dugong and dugong habitat for northern WA. A contemporary review of relevant literature by Holley and Prince (2008) found a lack of quantitative data on dugong abundance and distribution in the Kimberley. This is mainly due to the region's remoteness and lack of dedicated survey effort. The large tidal variation and water turbidity make standard aerial survey methods difficult to implement and the data difficult to interpret. To address the paucity of information, satellite tracking of dugongs has been trialed by Edith Cowan University and DEC, in collaboration with the Bardi Aboriginal rangers. This work has provided some insight into habitat utilisation and preferences of these animals. An individual animal tagged in Pender Bay moved southwards over a distance of approximately 100 kilometres to an area off James Price Point, which is known to support extensive subtidal seagrass communities. Dugong feeding has also been observed in both subtidal and intertidal seagrass communities.

Kimberley dugong populations have been traditionally harvested by indigenous people, who have good local knowledge of dugong distribution at certain times of the year. The North Australia Indigenous Land and Sea Management Alliance (NAILSMA), in partnership with the Kimberley Land Council (KLC), have commenced research into the dugong population and sustainable harvest in the region.

More information will be required to conserve and manage dugong populations in the Kimberley. For example quantitative data on dugong abundance and distribution in the Kimberley are needed. Presently little is known of seasonal movement patterns and important feeding or breeding areas. Although there is an indigenous cultural understanding of dugong distribution at certain times of the year, there are gaps in knowledge for other times and uncertainty regarding dugong density due to fluctuations in numbers of animals seen and hunted from year to year. Population structure and degree of connectivity between populations are unknown.

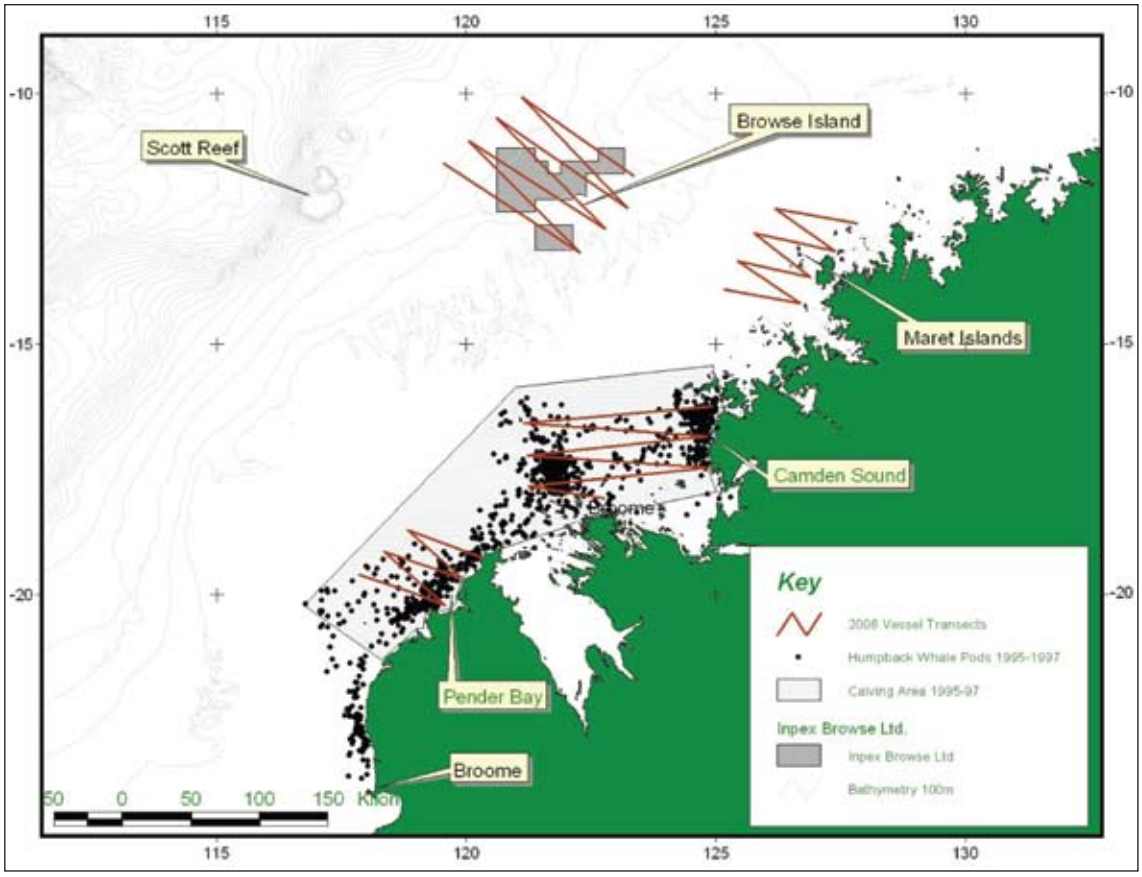


Figure 3: Locations of humpback whale pod sightings, vessel-based survey transects and approximate boundaries of the high density humpback whale calving and resting area in the southern Kimberley (source: Jenner and Jenner 2008).

Marine turtles

Six species of marine turtle occur in the Kimberley and all are listed as specially protected species under WA and Commonwealth legislation (Waples 2007). There are coastal beaches and offshore islands in the region that support marine turtle rookeries. Confirmation of this is provided by data from aerial surveys by INPEX covering much of the west Kimberley coast and islands which show some levels of nesting on nearly all islands supporting suitable beach habitat. Moderate density nesting activity was observed on Albert, Lamarck and Prudhoe islands and the highest density nesting activity was noted on the Lacepede Islands, Cassini Island, Maret Islands and East and West Montalivet Islands (INPEX 2008). The *State of the Fisheries Report* (Fletcher and Santoro 2007) discusses interaction between commercial fishing activities and protected species including marine turtles and describes management actions being taken to avoid or minimise impacts.

With the exception of unpublished work by INPEX on the Maret Islands and knowledge of the importance of the Lacepede Islands as nesting and inter-nesting habitat for green turtles (R. Prince, pers. comm., Waples 2007), little is known about population structure of turtles that utilise habitats in the Kimberley or the affinities these populations may have with other populations. Data gathered from long-term but intermittent tagging of sea turtles at a variety of rookeries on the north coast of WA, including the Kimberley region, are currently being analysed and prepared for publication by DEC scientists. There is a current study on the nesting activities of flatback turtles at Cape Dommett that has identified seasonal nesting patterns. Conservation Volunteers Australia (CVA) commenced a community-based turtle monitoring program on Cable Beach in 2006 and the first report on that program was published late in 2008 (McFarlane 2008). CVA has also recently commenced a turtle monitoring program near the Eco Beach resort south of Broome (G. McFarlane, pers. comm.).

Turtles tagged at Barrow Island (flatback turtles) and off east Java (green turtles) have been tracked from their respective tagging sites to waters off the Dampier Peninsula (seaturtle.org). This finding highlights the potential regional significance of the Kimberley and provides an insight into the relevant spatial scales that need to be considered when developing conservation and management plans for these species.

Seabirds

The region is important for seabirds and migratory shorebirds and a large variety and number of these species are present in the Kimberley on a seasonal basis. There are a number of recognised sites where migratory birds congregate, feed and breed in the Kimberley. The national and international importance of Roebuck Bay for migratory birds is recognized through listing of birds that visit these sites under agreements such as JAMBA and CAMBA and this area has been a focal point for a considerable amount of research attention (see Piersma *et al.* 2006).

An appraisal of field notes held by the WA Museum has provided some indication of the marine-related avifauna of the Kimberley region (R. Johnston, pers. comm.). The notes indicate that there are some important small islands for breeding seabirds in Napier Broome Bay in the far north Kimberley, to the north of Cape Voltaire in the Institut Islands and also in Admiralty Gulf. There are no breeding seabirds, and few shorebirds or northern hemisphere migrants known from the Maret Islands and this is likely to be the case for most of the islands with poorly developed mangal or other suitable foraging or nesting habitat (e.g. intertidal sand/mud flats and beaches/dunes). The significance of the Camden Sound area to seabirds is unknown and no important seabird sites are known on or around Koolan Island. These islands hold little habitat for waders and little mangal. Further south along the Dampier Peninsula, the intertidal flats and mangal around Packer Island are noted as important areas for both shorebirds and mangrove birds. The Lacepede Islands to the southwest have very important seabird rookeries. Intertidal areas on the adjacent mainland shore are thought to be well utilized by waders and terns but there are few records from this area.

The blocks of mangal at Cape Bossut are important bird areas and are at the southern extent of Kimberley mangal. Ramsar-listed wetlands occur at Roebuck Bay to the north and Eighty Mile Beach to the south of Cape Bossut.

Fish

A large diversity of fishes are known from the region, including endemics. Areas with high habitat diversity are presumed to support high fish diversity (B. Molony Department of Fisheries, pers. comm.). Most research on marine fish in the Kimberley region has been undertaken by the Department of Fisheries and is biased towards commercial species. The WA Museum has also gathered data on marine fish species and studies by AIMS of offshore reef communities have included investigations of fish species.

Creek systems, mangroves and rivers, and ocean beaches provide habitat, and hence fishing opportunities, for a variety of species including barramundi, tropical emperors, mangrove jack, trevallies, sooty grunter, threadfin, mud crabs and cods (Fletcher and Santoro 2007). Offshore islands, coral reef systems and continental shelf waters support species of recreational and commercial interest, including saddle-tail snapper and red emperor, cods, coral and coronation trout, sharks, trevally, tuskfish, tunas, mackerels and billfish. Wild pearl oysters, which are collected and then seeded for pearl production, are obtained from fishing grounds primarily off the Eighty Mile Beach, with smaller catches being taken around the Lacepede Islands. A detailed account of commercial and recreational fisheries that operate in the region is provided in the *State of the Fisheries Report 2006/07* (Fletcher and Santoro 2007) and Newman *et al.* (2003) make recommendations for priority research to inform fisheries management.

Protected sawfish utilize or pass through a range of nearshore habitats, including in the vicinity of rivers and open sandy beach habitats, but are unlikely to be common around offshore islands (B. Molony Department of Fisheries, pers. comm.). Speartooth shark and the northern river shark which are listed under the *Environment Protection and Biodiversity Conservation Act 1999* as 'critically endangered' and 'endangered', respectively, are also known from the region.

Management Issues

While human impacts on the Kimberley region's marine environment are generally very low relative to almost all of the world's marine ecosystems (Halpern *et al.* 2008) and relative to the mainland, significant management issues exist and will continue to emerge as development pressure increases. An overarching context for delivery of management, targeted science and conservation outcomes for the Kimberley encompasses principles of sustainable development, regional marine planning, implementation of a comprehensive, adequate and representative (CAR) system of marine protected areas (MPAs) and recognition of the strong interaction between land and sea in the region. Some important management issues can be addressed immediately on the basis of existing knowledge and some will require further work, including scientific research and survey designed to inform management options (see Wood and Mills 2008).

At the broadest level there are two key management issues relevant to the Kimberley: 1) biodiversity conservation and 2) environmental impact assessment (EIA) of development proposals.

Biodiversity conservation

Protection of the Kimberley breeding population of humpback whales has emerged as a key issue for decision making in relation to LNG development proposals and also the broader community. As discussed above, data on migration patterns and habitat utilisation in the southern Kimberley by humpback whales are sufficient to define approximate boundaries of a high density calving and resting area for this species that range from near the Lacepede Islands in the south to Camden Sound in the north. In view of this, it is possible to define important areas of habitat in the southern Kimberley that are under the State's jurisdiction and put in place a management framework to protect critical stages of the life histories of humpback whales in the region.

The considerable volume of research that has been conducted on migratory birds and their utilisation of intertidal flats in Roebuck Bay as foraging habitat, which point to the importance of the Roebuck Bay area

for populations of migratory birds including specially protected species and species listed under international agreements (CAMBA, JAMBA), also is sufficient to define and put in place a management framework to protect the area's values.

Further research is required to better understand the regional significance of the Kimberley for other specially protected marine fauna such as turtles and dugong. In particular, quantification of dugong and marine turtle harvest by traditional hunters is required to ensure such harvest is sustainable.

In the terrestrial environment, management of livestock and fire are key issues for the Kimberley (see Part B below). Managing these threatening processes will, among other things, help in controlling soil loss from Kimberley catchments. Heavy wet season rainfall (often associated with tropical cyclones) erodes soils, particularly in areas of catchments disturbed by stock and inappropriate fire regimes. Large volumes of eroded soil make their way into rivers that drain to the Kimberley coast. While little is known about the actual volumes of sediment transported into the marine environment from river catchments, or the ecological consequences of this sediment (if any) for marine communities, it is clear from case studies such as the Great Barrier Reef that managing elevated terrestrial sediment input to coastal environments is one of the most critical issues for the conservation of inshore reefs. The management of these issues can not be divorced from climate change effects that are predicted to include more frequent and intense storms, which as mentioned above strongly influence sediment inputs to the marine environment from terrestrial catchments. Nevertheless, actions in the river catchments to manage erosion and improve *in situ* soil retention will have positive consequences for coastal marine ecosystems.

A Marine Science Case for the Kimberley-Browse region has been prepared, after extensive consultation with stakeholders, for WAMSI (Wood and Mills 2008). This document identifies planning and management issues that require science inputs and sets out, at a high level, priority areas for research and a proposal for undertaking science in the region to address the identified planning and management issues. The WAMSI Marine Science Case is the logical platform from which to identify science needs and priorities.

Planning for, and environmental impact assessment of, development proposals

The Kimberley region is facing significant development growth in future years, particularly in the petroleum, aquaculture and marine-based tourism sectors. These activities will need to be carefully planned and managed for the long term environmental, economic, social and cultural good.

The WA and Commonwealth Governments have been working together on the selection and assessment of a preferred location for on-shore processing of LNG from natural gas reserves in the Browse Basin. The preferred site for an LNG precinct has been announced as being in the vicinity of James Price Point on the Dampier Peninsula. A proposal for that site will undergo EIA under State and Commonwealth legislation, before being considered for approval. The EIA will require a wide suite of tactical marine scientific studies to inform decision making that will follow. These studies will contribute to increased understanding of the ecological values and key sustaining processes that operate in the region.

Until the Government implemented the strategic site selection process for an LNG processing precinct in the Kimberley, planning for large-scale development was proponent-driven. In the case of smaller scale development/activities including pearling, aquaculture and marine tourism, proponents are still largely responsible for selecting the sites for their activities in the Kimberley. This approach inevitably leads to conflict between uses as the intensity and diversity of use increases. This highlights the need for integrated marine planning at the region scale. Regional marine planning in advance of the projected growth in development proposals over the short to medium term is likely to deliver ecological and other benefits for the region, by identifying important areas to be included in marine conservation reserves and areas that may be suitable for development. Informed regional marine planning should ideally be underpinned by targeted strategic science.

Norm McKenzie, Tony Start, Andrew Burbidge, Kevin Kenneally and Neil Burrows

Overview

The Kimberley extends from sub-humid to semi-arid areas and covers a variety of different geological basements. These differences are reflected in the distinctive geomorphologies, soil, landscapes and biotas of the north, central, south and eastern Kimberley, and have determined their different land-use histories and contemporary land condition. In these terms, five biogeographical regions (10 subregions) are recognised in the Kimberley (Thackway and Cresswell 1995, McKenzie *et al.* 2003), that provide a framework for planning and action.

In this section, we review the information base then characterise the bioregions to identify their different contributions to Kimberley diversity (treated here as a mosaic of regional ecosystems). Then we summarise the biodiversity values of Kimberley ecosystems and identify special features, communities, clades and species that should be a particular focus for management because of rarity, special value, vulnerability or imminent risk.

Next, we review the condition and trend of the ecosystems in each bioregion, and provide a schematic model of the soil nutrient, hydrological and inter-species processes that maintain the compositional diversity of savanna because it is the matrix in which all of the Kimberley's other ecosystems and special features are set.

Finally, we identify priority management needs, particularly strategic actions that will mitigate degrading processes throughout the Kimberley and protect or rehabilitate whole suites of ecosystems and species. Healthy country is more productive, both in economic and biodiversity terms (Whitehead *et al.* 2000, Start 2003). The most cost effective conservation strategy is to protect, restore and maintain functional landscapes and systems, rather than trying to preserve small remnants or focussing only on localised, patch-scale remedial actions such as site restoration. A cross-tenure approach needs to be taken in controlling the threatening processes both to maintain the unique values of the Kimberley and to allow sensible development and other activities where appropriate. This process must have a foundation of strong science to inform planning, decision making and, where necessary, restoration.

In terms of its climate, landscapes and biodiversity, the Kimberley is part of northern Australia's tropical savanna biome, so ecological studies and land management lessons from other parts of this savanna bear on its management, especially those from equivalent sub-humid and semi-arid regions in the Northern Territory. Because of uncertainty and knowledge gaps in understanding the processes threatening Kimberley ecosystems, management needs to be implemented in an adaptive management framework, ensuring that best available information is fully utilised and that managers learn by doing (e.g. Williams *et al.* 2002, Burrows 2005).

Information-base

Literature

Attachment 4 (Part B: Terrestrial) lists all references cited herein, and is divided into four sections: overviews, surveys, reserve recommendations and landscape processes. The most recent scientific literature review (Waples 2007) includes 992 entries, including documents on the Kimberley's ecological values, conservation reserve system, wildlife surveys, historic exploration notes, Aboriginal ethnobotany and economic planning. It focuses on literature accessible through formal publications and government reports, but undoubtedly overlooks many less formal articles. For instance, projects undertaken by consultants for industry were often unpublished and can be difficult to identify.

Environmental maps and other spatial data

A total of 240 datasets have been identified that contained information on Kimberley biodiversity (see Handasyde 2006, Waples 2007). They include broadscale datasets that cover a large area beyond the Kimberley such as vegetation mapping of the north end of Australia by the Tropical Savanna CRC, and datasets specific to particular ecosystems such as flora and fauna records from the Kimberley Rainforest Survey (McKenzie *et al.* 1991). A full list of the datasets can be found in Waples (2007).

Environmental maps that provide a first approximation of the regional ecosystem boundaries (the mosaic) and cover the entire Kimberley include the1:250 000 surficial geology and 1:250 000 vegetation maps (Beard 1979, supplemented by the rainforest classification maps by Kay *et al.* 1991, and by forest cover maps derived from satellite images by Behn 2001). In addition, land-system maps cover large areas of some bioregions (e.g. Speck *et al.* 1960, 1964; Stuart *et al.* 1970). 'Google Earth' provides an aerial view of vegetation-types in the context of topography.

Kimberley landscapes support a variety of vegetation including hummock, tussock and bunch grasslands, shrublands, tree steppe, woodlands, riverine forest, mangrove, rainforests and paperbark swamps. While broadscale mapping of mangrove, rainforest, riverine forests and paperbark forests from the satellite images was considered adequate, image analyses did not reliably discriminate savanna vegetation-types (woodlands, tree steppe, shrublands and grasslands) or height classes (Behn 2001). The savanna communities that dominate the Kimberley have not been mapped at a scale with sufficient resolution to adequately inform fire management programs.

Administrative and biogeographic regions

For administrative purposes, the Kimberley is divided into four local government areas: Broome, Derby-West Kimberley, Halls Creek and Wyndham-East Kimberley. For conservation planning purposes it encompasses three biogeographic regions (Northern Kimberley, Central Kimberley and Dampierland) and parts of two others (Victoria-Bonaparte and Ord Victoria Plains) (Fig. 4). The bioregions are characterised in Attachment 1, but more detailed descriptions can be found in May and McKenzie (2003).

Biodiversity data

There has been a long history of botanical and zoological collecting in most parts of the Kimberley with voucher specimens lodged in herbarium and museum collections, particularly the collections of the WA Herbarium and the WA Museum. These records normally include locality data and, except for many invertebrate groups, are available through searches made on-line or by request. Literature searches often reveal the existence and location of early collections of invertebrates as well as vertebrates and plants.

In addition, numerous biodiversity and taxon-specific surveys have been undertaken. Some cover entire ecosystems (mangrove, rainforest, Devonian ranges), while others have focussed on sampling the landscapes of an individual conservation reserve (e.g. Prince Regent, Purnululu) or a particular area or situation (Dampier Peninsula, Edgar Ranges, North Kimberley islands, Mitchell Plateau), or on a particular group of organisms (flora, birds, mammals, frogs, reptiles, fish, land snails or spiders etc) either locally or Kimberley-wide. Many of the relevant studies are listed in Attachment 4. Other surveys have been carried out on Australian Wildlife Conservancy properties, Buccaneer Archipelago, Napier, Oscar and Ningbing Ranges, Victoria-Bonaparte land snails, Fitzroy River fish and lower Ord fish (e.g. Storey 2000).

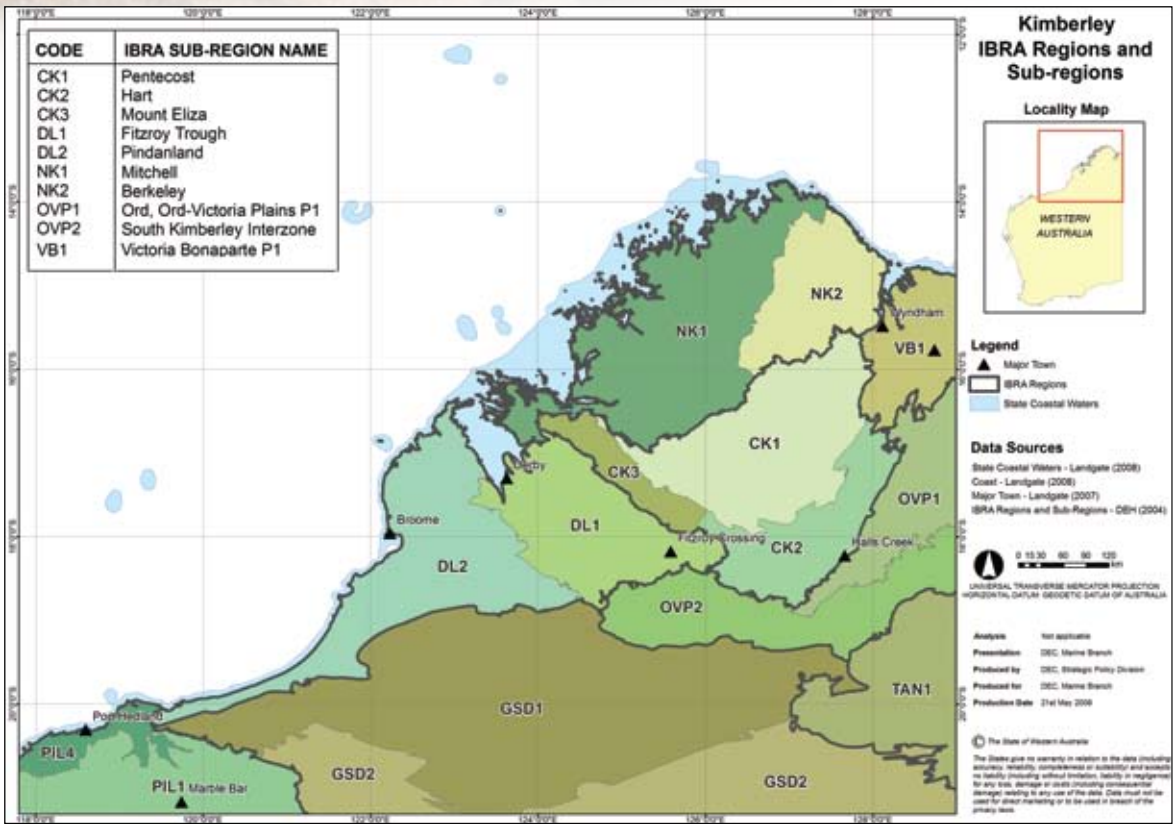


Figure 4: Terrestrial Bioregions and Sub-regions of the Kimberley. NK = North Kimberley, CK = Central Kimberley, DL = Dampierland, VB = Victoria-Bonaparte and OVP = Ord Victoria Plains.

Surveys of fauna in the Kimberley have identified 76 species of native mammal, 295 bird species, 178 species of reptile, and 42 named species of native frogs. Overall species diversity is highest in coastal, high rainfall areas and sandstone ranges (Woinarski 1992). In the Australian Mammal Audit (McKenzie and Burbidge 2002), the Kimberley shows a rich mammal fauna with high endemism and low attrition rates in some areas. Of note, there have been no mammal extinctions in the north Kimberley, though the status and distribution of a number of medium size mammals is of concern (McKenzie and Burbidge 2006). Further, the Kimberley has the highest diversity of frog species in WA. Although work on the invertebrates of the Kimberley is extremely limited (e.g. Solem 1988), many of the 126 species listed as endangered are land snails.

The Kimberley has been listed as a National Biodiversity Hotspot: 230 plant, 16 fish, 10 frog, 31 reptile, 2 bird and 6 mammal species are known to be endemic to the region (e.g. Wheeler 1992), and strongly localised patterns of endemism characterise some invertebrate groups such as the camaenid land snails and earthworms (e.g. Solem and McKenzie 1991). The endemism is not restricted to the sandstone uplands and rainforest patches of the high-rainfall north Kimberley, it is also well documented from limestone ranges in the south-western Kimberley and the Victoria-Bonaparte Bioregion.

In general, the available data are inadequate to assess the real status of many rare or locally distributed species that may warrant gazettal as threatened. There has been no systematic biodiversity survey of an entire Kimberley bioregion or subregion, and no detailed plant or animal surveys of savanna ecosystems on the alluvial plains of the Fitzroy Trough and South Kimberley Interzone Subregions.

General reviews of Kimberley biodiversity, its conservation, condition and trend

Kimberley Regional Planning Study (Burbidge *et al.* 1991)
Biodiversity Audit (May & McKenzie 2003, McKenzie *et al*. 2003, Gordon & McKenzie 2004)
Kimberley Regional Plan (Portlock *et al*. 2001).
Kimberley Regional nature conservation strategy (DEC 2008, unpublished draft)
Kimberley Biodiversity Review (Waples 2007)
Tropical Savanna CRC's Ord-Bonaparte project (e.g. Sandercock 2004, Wolanski *et al.* 2001)
Handasyde (2006) inventoried publications and available biodiversity data-sets on the terrestrial environment for the Kimberley, with the main focus on the mainland and on issues relevant to fire management (e.g. Craig 1997, 1999).
AusRivas project (Halse *et al.* 2001).
WA State of Environment Report (EPA 2007).

Biodiversity values

Tropical savanna ecosystems

These ecosystems vary in their vegetation structure and species composition according to factors such as substrate, rainfall, biogeographic history and disturbance history (e.g. Williams *et al.* 2007), and form the matrix in which the Kimberley's other ecosystems and special features are set. An array of savanna ecosysyems are recognised in the Kimberley, each characterised by specific tree and grass commuities (perennial hummock and tussock grasslands, annual cane grasslands etc), shrublands, tree steppes and woodlands on:

- the various soil surface types found in each bioregion (eluvial, alluvial, aeolian; silt, clay, sand), and
- each of the geomorphic units expressed by the stratigraphy (rock formations recognised) in each bioregion (various sandstones, volcanics, granites, limestones, mudstones, siltstones etc) (e.g. Gellatly and Sofoulis 1973).

Riverine and freshwater swamp ecosystems

Wetlands, including water courses and their riparian zones, are an important resource for waterbirds and provide refugia during the dry season for many savanna species, as well as containing a vast array of aquatic species that are often poorly documented (e.g. Halse 2000, Loh *et al.* 2001). The riverine wetlands also provide one of the Kimberley's few forests, a discrete vegetation community with a paperbark and rivergum canopy and a characteristic vertebrate fauna. Four wetlands are recognised for their significance at a global level and are listed under the Ramsar Convention. Only one of the four Ramsar-listed wetlands in the Kimberley is within a nature reserve although nature reserves and marine parks recommended in Burbidge *et al.* (1991) and Wilson (1994) would cover all, or portions, of the remaining three sites. A further 21 sites are considered nationally important wetlands. DEC's Wetlands Database Project 2005 provides online information on the location, tenure, hydrology, geomorphology, flora and fauna of significant wetlands in the Kimberley. The Australian Wetlands Database contains information on the wetlands of international (Ramsar Convention) and national importance (Environment Australia 2001), their physical and ecological features, threatened flora and fauna, migratory fauna, social and cultural values, threats and management activities.

Coastal ecosystems

The Kimberley coast provides habitat for important vertebrates such as estuarine crocodiles, mangrove birds and mammals, migratory shorebirds, seabirds and marine turtles, although more detail on their ecological and community requirements and interactions is needed to optimise management programs. While there are considerable data on the birds and bats of the mangrove communities (e.g. Johnstone 1990, McKenzie and Rolfe 1986), the composition of arboreal mammals and reptiles that use the mangal is still poorly understood.

Some of the largest patches of mangrove in Australia occur along the Kimberley coast. They have a total area of 140 000 hectares, are rich in species, and considered to be among the most pristine mangals in the world as they have not been open to logging or fragmented by coastal infrastructure. Stands comprise up to 18 tree species and their fauna is both rich and distinctive. Relevant publications include Pedretti and Paling (2001), Semeniuk *et al.* (1978), Wells (1982), Hutchings (1995), Hanley (1998), Johnstone (1990), Bridgewater and Cresswell (1999), Saenger (1998), Wells and Bryce (1996), Semeniuk (1980, 1982, 1985), Messel *et al.* (1987), McKenzie and Rolfe (1986) and Thom *et al.* (1975). Mangals provide coastal protection by reducing the shoreward effects of storm surges associated with cyclones, and also create an interface between marine and fresh waters that reduces the effects of nutrient runoff, roles on which adjacent corals and seagrass ecosystems are thought to depend (see Part A above and Bridgewater and Cresswell 1999). They also provide nursery and breeding habitats for important fisheries along this coast (Pedretti and Paling 2001), and habitat for saltwater crocodiles. Given the apparent resilience of this ecosystem, there are no major perceived immediate threats (although see Wolanski *et al.* 2001 re Cambridge Gulf), but their arboreal mammal and reptile faunas need detailed study, and the potential effect of feral pigs needs to be investigated.

The Kimberley includes many estuaries and tidal mudflats. OzEstuaries online database includes data on the condition of 80 estuarine sites in the Kimberley as pristine, with four considered to be largely unmodified and one (Ord River estuary) modified. Extensive tidal mudflats characterise Kimberley coastlines, particularly its estuaries, inlets and bays. Geomorphological studies of mudflats in Cambridge Gulf have been undertaken (Wright *et al.* 1972, 1973, 1975, Thom 1975, Wolanski *et al.* 2001) and Semeniuk (1980, 1981, 1985) has described sediments of the tidal flats of King Sound. Roebuck Bay has received a great deal of attention (see Part A above) and there is ongoing collaborative research on the invertebrate fauna and relationship with sea, shore and migratory birds (de Goeij *et al.* 2003, Rogers *et al.* 2003, Piersma *et al.* 2006). While Roebuck Bay studies have identified a high invertebrate and shorebird biomass and diversity, this research has not been repeated at other similar sites and it is not known whether this level of biodiversity and productivity is unique to Roebuck Bay or more widespread across the Kimberley. Sites such as Eighty Mile Beach and Roebuck Bay are considered of international significance given the numbers and diversity of birds that feed in these areas seasonally, and are listed Ramsar sites. There is a reasonable amount of published literature on sea and shorebirds in the Kimberley (e.g. Storr 1980, Johnstone 1990, Woinarski 1992, Watkins 1993, Tulp and DeGoeij 1994, Collins 1995, Barrett *et al.* 2003, Hickey *et al.* 2003). Long-term research programs have been active through Birds Australia (the Broome Bird Observatory) and the Australian Wader Study Group, and limited surveys of seabird breeding islands have been conducted (e.g. Burbidge and McKenzie 1978, Burbidge *et al.* 1978). However, there is a need to maintain a monitoring program for these islands. The north-west of Australia is a first stopping point for many of these bird species on their migratory route from southeast Asia. The islands of the Kimberley and the regions intertidal coastal environment and wetlands, contain a number of important areas, not all of which have been identified, where these species congregate, feed and rest.

Short steep beaches can be found between rocky headlands on the many coastal islands of the Kimberley. These beaches comprise coarse terrigenous material, sometimes including pebble beaches in areas where there are basalt or dolerite outcrops. Consolidated beach dunes behind the beaches are usually well vegetated with beach spinifex and, further back, with hummock grasslands stands of *Pandanus* and patches of semi-deciduous monsoon vine thicket. They are rich in vertebrates such as mosaic-tailed rats, black whip-snakes and skinks, and the fore-dunes are known nesting sites for marine turtles.

A high proportion of the Kimberley shoreline is rocky. Although surveys record a variety of vertebrate species foraging in this environment, including water rats, northern quoll, mangrove kingfishers, oystercatchers and other wading birds, olive pythons, and various lizards, there have been no specific studies of rocky shore communities and their relationship to adjacent communities such as the mangrove, sandstone and volcanic country. There are also spectacular boulder bars presumed to have been generated by tsunamis (e.g. on Darcy Island), that may provide an understanding of tsunami threats to the Kimberley coastline.

Rainforest ecosystems

Between 1987 and 1989 a broad scale ecological survey was undertaken of the Kimberley rainforests. Data were collected on compositional patterns of biota, disturbance and physical characteristics of the environment. The results of this survey provide information on soil and landform, invertebrate and vertebrate fauna, floristics, vegetation structure and spatial distribution of rainforest patches (McKenzie *et al.* 1991). About 1 500 patches are scattered across 170 000 square kilometres of the Kimberley. They have a distinct structure, are rich in species not found in the surrounding savanna, and occur as small, isolated patches on hillsides and scree slopes, in gorges and gullies, in swamps, along rivers and on coastal sand dunes. The average patch has an area of three hectares and few exceed 20 hectares; most are in the rugged high rainfall north-west. They are characterised by high levels of invertebrate endemism, and numerous plants and vertebrates depend on the archipelago of patches for their persistence in the region. Nearly 25% of the 2 000 species that comprise the Kimberley flora were recorded in the rainforests, and about a third of these are confined to them.

Unlike savanna communities, a high proportion of rainforest plants produce succulent fruits that are an essential food resource for many of the region's fauna. A total of 141 bird species was recorded in Kimberley rainforests (45% of the Kimberley terrestrial bird fauna), and some of the most colourful of Western Australia's birds rely on them (figbirds, yellow oriole, spangled drongo, rainbow pitta, orange-footed scrubfowl, emerald dove and rose-crowned pigeon). The patches are part of a great corridor of monsoon forests extending through South-east Asia and into Australia that is important for the seasonal migration of birds such as koels and channel-billed cuckoos. Many of the small immobile species endemic to the Kimberley have only been recorded in rainforest patches. This includes 90% of the earthworms and 48% of the land snails.

Troglobitic and stygofauna ecosystems

There is a significant subterranean fauna in the Kimberley containing both troglobitic and stygobitic elements. This poorly studied group is known from limestone ranges of the east and west Kimberley, alluvial aquifers of Ord River Irrigation Area (Humphreys 1995, 1999) and Argyle Diamond Mine (Humphreys 2003), sandstones and offshore islands (Wilson and Keable 1999). The fauna is typically locally endemic and some elements represent globally significant basal and/or relictual phylogenetic lineages (Cho *et al.*, 2005, Wilson and Keable 1999, Wilson and Ponder 1992).

Special landscapes, ecosystems and species values (see Attachment 2 for details)

- A largely intact flora and fauna in the north west margin of the Mitchell Subregion, including many endemics as well as mammals that are extinct elsewhere in Australia. Its sandstone communities show high species endemism and ecosystem diversity.
- A submerged coastline with extensive coastal archipelagos that form virtually weed and feral animal free microcosms of the adjacent mainland and an opportunity to protect intact, healthy ecosystems.
- Napier, Oscar and Ningbing Ranges, the stranded remnants of Devonian barrier reef system. Rivers traversing the ranges have created spectacular gorges. There are many species and genera endemic to these ranges and extensive cave systems with troglofauna.
- Rainforest patches have endemic invertebrates and act as seasonal refugia.
- Mound springs and swamp rainforest.
- Wetlands such as the Camballin Floodplain.
- Grasslands associated with black soils in Dampierland (Roebuck Plains – *Sorghum*), Kimberley Interzone (Mitchell Grass) and Victoria-Bonaparte (Rice Grass & *Sorghum)*.
- Extensive coastal mudflats which support numerous migratory birds (e.g. Roebuck Bay and Eighty Mile Beach)
- Tropical laterite flora on Mitchell Plateau, with a palm-dominated landscape, is unique in WA. The Cape Bougainville rainforest on laterite and volcanic surfaces is the largest single rainforest patch in the Kimberley.
- Many island and mainland beaches are turtle breeding sites.

Ongoing degradation of regional ecosystems and special features

Attachment 3 provides an overview of condition and trend in the landscape biodiversity of the five Kimberley bioregions. Pastoral influences and changed fire regimes are a ubiquitous theme. Below we discuss Kimberley ecosystems and special features that have strategic, cross-tenure priority for on-ground management action.

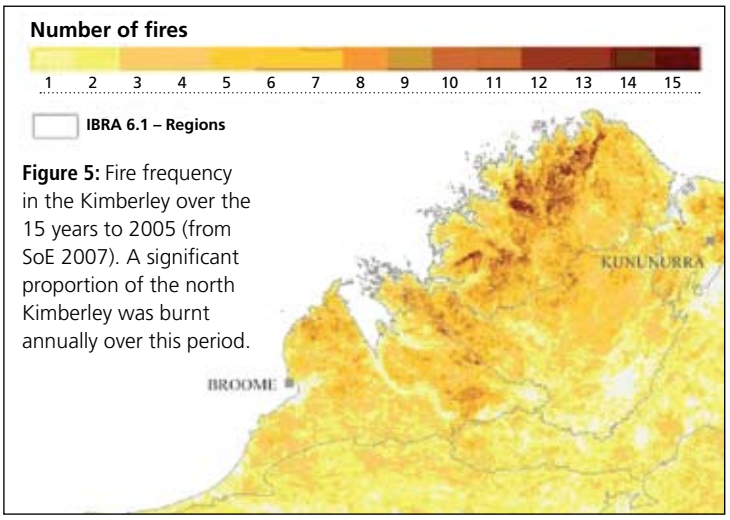


Figure 5: Fire frequency in the Kimberley over the 15 years to 2005 (from SoE 2007). A significant proportion of the north Kimberley was burnt annually over this period.

Above left Degraded pindan shrubland severely impacted by too frequent burning is a common feature of the Dampierland Bioregion.

Savanna and riverine ecosystems

Fire is a natural environmental factor that has shaped tropical savanna ecosystems over millennia. As well as lightning-caused fires, Aboriginal people lit fires extensively to hunt game, to regenerate food and medicinal plants, or to "clean up country". Since European settlement there has been a reduction in traditional Aboriginal use of fire because in many areas people are not 'on country' as they were in the past and land use and tenure have changed. The fire regime has changed from one dominated by mild, patchy fires mostly lit early in the dry season, to mostly intense, large fires later in the dry season (Russell-Smith *et al.* 2002 and 2003, EPA 2005, Radford and Anderson 2006). In most places, fires are also more frequent than they once were (see Fig. 5). The fire situation in the Kimberley is of such concern that in 2005 the then Minister for the Environment requested that the Environmental Protection Authority (EPA) review environmental aspects of fire in the Kimberley and interior of the State (EPA 2005).

The compositional complexity, vegetation structure and soil structure of tropical savanna ecosystems have changed, and continue to change, under the current regime of extensive, frequent, intense, late-dry season fires and grazing by feral herbivores (e.g. Roth 2004). As well as large scale degradation of the structural and floristic integrity of vegetation and fauna habitats, these changes affect landscape productivity through nutrient erosion and hydrological change, particularly infiltration/runoff coefficients (e.g. Braithwaite and Muller 1997; Ludwig *et al.* 1999, 2005; Russell-Smith 2006), and are ubiquitous. They are particularly severe in the semi-arid Ord and Fitzroy Trough Subregions because their fertile alluvial plains offer fewer natural barriers to fire and stock. Pastoral development in the rugged northern Kimberley is both more recent and more localised, but the soils of its landscapes are shallow, skeletal and more sloping on average, and rainfall events are more frequent and heavier. In the northern Kimberley cattle have emigrated from pastoral leases using riparian and other corridors into conservation reserves, Aboriginal land and unallocated Crown land. Changes include simplified vegetation structures dominated by annual grasslands and with fewer perennial trees, shrubs and grasses and loss of obligate seeders (e.g. Russell-Smith *et al.* 2002, 2001, Dyer 2001, Woinarski *et al.* 2004), increased soil erosion including the loss of leaf litter, organic-A and mineral-A soil horizons, greater runoff volumes and velocities, with increased alluvial deposition on footslopes, floodplains and in estuaries, and as bedload in rivers, and more severe flood events in drainage lines with high flow velocities that strip riparian zone vegetation and enhance weed invasion (Fig. 6).

Above Introduced siratro (*Macroptilium atropurpureum*), a native of tropical America, is an aggressive weed seen here invading coastal monsoon vine thicket in the Dampierland Bioregion.

Above right Introduced black buffel grass (*Cenchrus ciliaris*), a native of Africa and India, causes considerable ecological change, seen here invading coastal dunes and sand plains in the Dampierland Bioregion.

Consequences include loss of savanna biomass and complexity; disruption of granivorous mammal and bird guilds during the resource bottleneck of the late-dry to early wet season (Franklin 1999, Woinarski *et al.* 2001), contraction/loss of rainforest patches (McKenzie *et al.* 1991, Russell-Smith and Bowman 1992), decline and extinction of medium size mammals (McKenzie *et al.* 2006, Woinarski *et al.* 2001 – note the Kimberley has not been colonised by foxes and rabbits), occlusion of drainage systems and loss of river pools (e.g. Ruprecht and Rogers 1998). The scale of this process is so great on the mainland that the coastal islands have a paramount protection role for the Kimberley's biodiversity. Inappropriate fire is the main driver of these changes but appropriate fire offers a management tool for reversing it (see Russell-Smith *et al.* 2002, 2003, EPA 2005).

Introduced plants thrive in the landscape where cattle and fire impacts have reduced the integrity of the native vegetation. Riparian areas have a wide variety of weed species, but the broader landscape is threatened by a few weed species that are more tolerant of low moisture levels such as buffel grass. Buffel is allelopathic, further simplifying the vegetation. This effect is particularly severe in riparian areas. New weeds are occasionally found in the Kimberley such as rubbervine, *Vachellia nilotica* and parthenium, indicating the need for stronger quarantine and surveillance measures. An issue that is receiving increasing attention is the westward spread of the cane toad toward WA. Significant efforts are being made to delay the arrival of the cane toad into WA, and to identify biodiversity assets at risk so that focussed protective measures can be implemented.

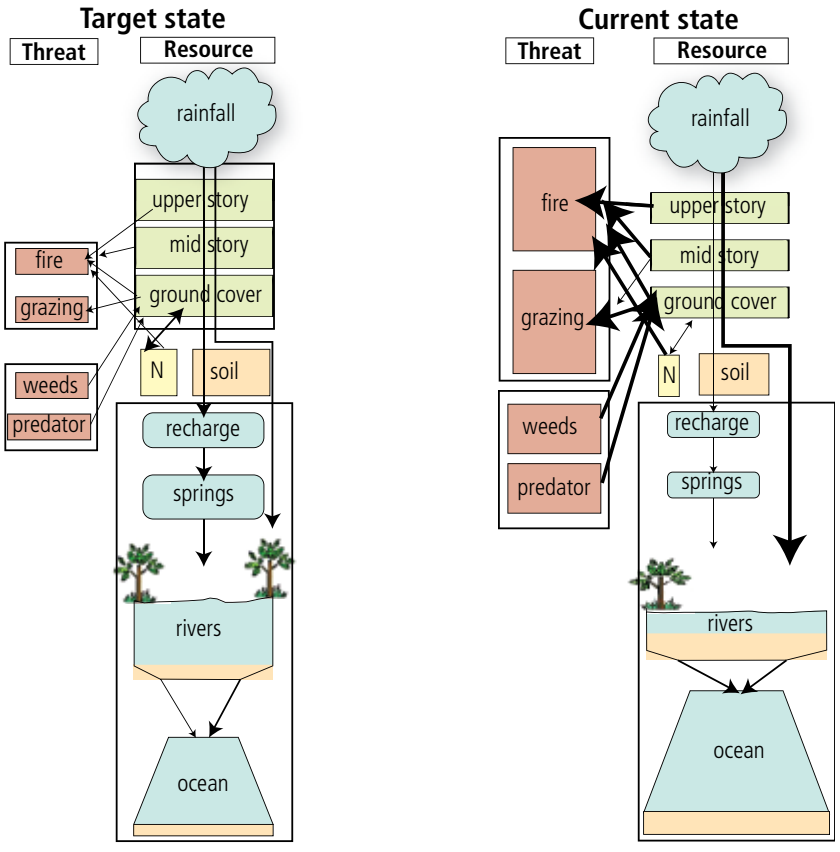
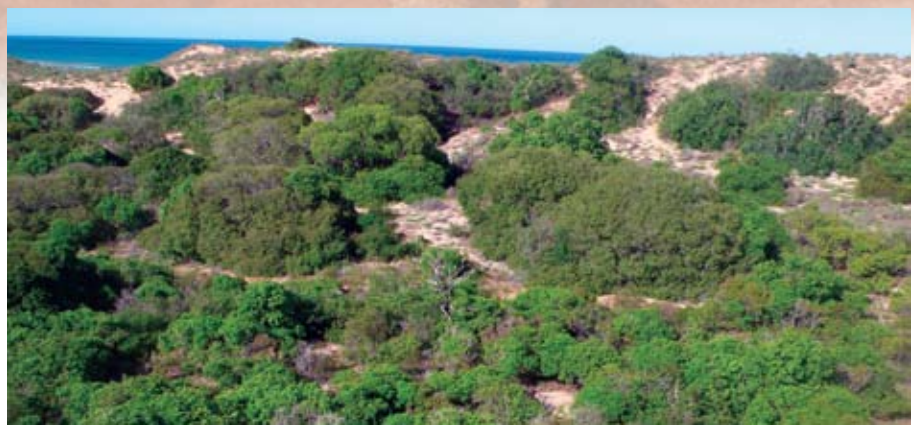


Figure 6: Conceptual systems model for Kimberley savanna (from DEC 2008): relative condition and threat targets are indicated by box size, relative resource movement by arrow weight and 'N' represents soil nutrients.



Rainforest

Fire has had a strong influence on the localised distribution and boundary characteristics of rainforests across northern Australia (e.g. Russell-Smith and Dunlop 1987, McKenzie and Belbin 1991). The size and shape of persisting patches often reflect the level of protection from fire offered by surrounding landforms and vegetation, and patches used by feral stock are the most frequently burned. As rainforests were prime food-gathering areas, Aborigines would not burn them, and would try to protect them from fires by burning the grassland around a rainforest patch early in the dry season (Mangglamarra *et al.* 1991). Fires burning in the wet or early dry seasons would generally not penetrate rainforest, which were too moist to burn at these times. However, rainforests are vulnerable to, and are degraded by, intense fires late in the dry season. Unfortunately, the small size of the rainforest patches has made them particularly vulnerable to disturbance. Patches in cattle country are being trampled, opened, invaded by flammable savannah grasses, and are contracting in size. They need to be fenced to exclude grazing stock, and savanna fire regimes need to be managed to prevent late dry season wildfires penetrating and damaging patches.

Above Closed-canopy rainforests are found on rugged sandstone slopes in the North Kimberley Bioregion.

Above left Coastal rainforest (evergreen and deciduous monsoon vine thickets) in the Dampierland Bioregion is listed as a Threatened Ecological Community.

Below Rainforests on lateritic scree slopes are found on Cape Bougainville, Mitchell Plateau and islands such as the Marets in the North Kimberley Bioregion.

Islands

The more than 2 500 islands along the Kimberley coast (340 have an area exceeding 20 ha) have an important role in Australian fauna conservation (Burbidge 1991). Not only do the islands support populations of various Kimberley endemic species (such as scaly-tailed possum, monjon - a rock-wallaby, Kimberley rock-rat, black grass-wren, rough-scaled python, Kimberley taipan, at least 15 lizard and frog species, and numerous plant, land snail and earthworm species), they are also refugia for a variety of threatened mammals that have disappeared from large areas of the mainland (e.g. golden-backed tree-rat, golden bandicoot, northern brown bandicoot, northern quoll and pale field-rat). Forty of the Kimberley's 76 terrestrial mammals are now known from the islands.

Not only do the islands provide a microcosm of the adjacent mainland's geological and biological diversity, they are also relatively isolated from many of the threatening processes affecting mainland ecosystems. In almost all cases, the Kimberley's coastal and off-shore islands are weed-free, have had no pastoral use and have not been colonised by feral animals. Exceptions are Koolan and Cockatoo which have been mined for iron ore since the 1960s, and Sunday and Adele which have introduced rat populations. Most of the islands do not show the fire-induced vegetation and soil changes apparent in the mainland savanna although the frequency of dry season fires appears to have increased in the last decade, along with increased visitor numbers (tourism etc). For instance, there have been extensive fires on both Augustus and Bigge, the two largest islands, during the last 5 years. DEC is currently surveying biodiversity on 20 of the largest islands to develop a conservation management plan in collaboration with traditional owners.

Above Coronation Island in the North Kimberley Bioregion showing rainforest on basalt (Carson Volcanics) and mangroves fringing the sheltered embayment.

Left Golden bandicoots (*Isoodon auratus*) persist in the North Kimberley and on some islands. They have disappeared from arid and semi-arid Australia over the last century.

On-ground conservation management priorities for regional ecosystems and special features

Better fire management

A change in current fire management, and feral animal and stock control practices across the entire landscape, including conservation reserves, is required to control erosion, vegetation simplification and fauna declines in savanna ecosystems (Legge *et al.* 2008). An early dry season mosaic fire regime needs to be imposed in an adaptive management framework to acquire the 'response' data needed to fine tune the regime for the various savanna ecosystems. Late dry season fires will need to be actively suppressed where possible.

The program needs to deliver biodiversity conservation benefits on-ground and over areas much greater than just the existing conservation reserve system. Much of the Kimberley is Aboriginal land and given the remoteness of the regions and sparsity of settlement, the positioning of logistical and human resources will be a major activity, so implementation will need to involve collaborations with local Aboriginal communities. DEC's Kimberley region staff already undertake ground and aerial burning programmes in various parts of the Kimberley in conjunction with the Fire and Emergency Services Authority (FESA), and often in collaboration with Aboriginal communities. Following the development of a Kimberley regional fire management plan, this program needs to be significantly expanded in close collaboration with FESA, indigenous communities and pastoral organisations, particularly in applying late wet, early dry season fire mosaics for protection of lands at landscape scales. Logistical and on-ground human resources will need to be expanded as part of costing, planning and implementing a wider program. Training and deployment of contract Aboriginal 'fire teams' is a promising recent development. DEC is collaborating in the EcoFire project (http://www.savanna.org.au/km/kimberley_ecofire.html) with the Australian Wildlife Conservancy, Kimberley Land Council, FESA, Department of Agriculture and Food and Pastoralists and Graziers Association.

There needs to be increased attention to fire management and weed control and closer attention to the spread of 'pasture improvement' species, particularly some grasses. There are opportunities for closer collaboration in monitoring and management of pastoral lands for sustained biodiversity, leading to healthier country for all concerned.

Below Populations of the white cypress pine (*Callitris columellaris*) have been dramatically reduced by the impact of frequent, hot fires.

Control of introduced herbivores

Feral cattle, donkeys and pigs need to be removed from conservation reserves and unallocated Crown land, and fenced out of rainforest patches that show evidence of substantial contraction (McKenzie *et al.* 1991). DEC's Kimberley region staff have appropriate experience in relation to methods, staffing requirements, logistics and costs. A new bait for feral pigs has recently become available.

Other activities

- Further investigation of the current status of individual species and particular savanna ecosystems is needed to better understand the specific impacts of threatening processes. As with the cane toad, the impact of feral cats needs to be assessed in the Kimberley.
- Develop and implement a Kimberley island management plan in collaboration with traditional owners.
- Priorities for wetland conservation have been assessed by the WWF (Vernes 2006). This report identifies a need to continue to monitor the water quality of wetlands in the Kimberley because, while most wetlands were in good condition, there was indication of some degradation, in particular in areas subject to disturbance by cattle and in river systems subject to flow impoundment such as the lower Ord (e.g. Davies 2000). Surveys of wetland flora and fauna are required in the Kimberley.
- Provide a new vegetation map for the Kimberley as a better basis for conservation planning and activities.

Conservation Reserve System priorities

There are 2.3 million hectares of conservation estate (national parks, nature reserves, conservation parks) in the Kimberley, or 4.4% of the Central Kimberley Region's land area, 14.6% of North Kimberley, 1% of Dampierland, 5.9 % of Ord Victoria Plains and 5.8% of Victoria-Bonaparte. The vegetation associations mapped by Beard (1979) are used by conservation planners to represent the pattern of regional ecosystems across the Kimberley. Only 73 of the 300 vegetation associations recognised in the Kimberley occur in the reserve system (May and McKenzie 2003, Graham and McKenzie 2004). Furthermore, these associations are mapped at a relatively coarse scale, and even a cursory on-ground inspection reveals finer-scale mosaic patterns within these map units, especially the woodland, mangrove and rainforest units, that reflect differences in species composition associated with changes in local edaphic factors such as soil, topographic location and underlying geology. If standardised, updated and overlaid on the vegetation maps along with a digital elevation model and the rainforest classification maps, the 1:250 000 surficial geology maps can provide a more refined representation of ecosystem boundaries for planning purposes. However, considerable ground truthing will be required and some vegetation types occur in patches that are too small to map at 1:250 000 scale. These include mound springs and the ephemeral wetlands on sheet sandstone.

The comprehensive and adequate representation of vegetation communities in the reserve system is a priority issue in the Kimberley. Several areas, including many of the coastal islands, have been proposed for reservation since the 1970s (Burbidge *et al.* 1991), and vegetation mapping at a resolution of 1:100 000 or better is urgently needed not only to guide fire management programs, but also to further refine the existing reserve system.

Kimberley rainforest patches are too dispersed and compositionally dissimilar to be adequately represented by existing conservation reserves. Although a series of additional conservation reserves have been proposed to ensure adequate representation of Kimberley rainforest types, the community is so dispersed that the persistence of its richness in the region relies on patches being functionally networked, which cannot be guaranteed by any feasible reserve system so there must be active management and protection of patches both inside and outside reserves.

Information Gaps

While there is a reasonable amount of published and unpublished data and information on the Kimberley, most of these data are broad scale with poor resolution, patchy with varying levels of resolution, or specific to a site (Waples 2007). Information can also be difficult to access for a variety of reasons, including information collected by consultants to industry and private research data.

Survey effort has generally focused on DEC managed lands and a considerable proportion of specimens (and thus species information) have been collected along roads, further biasing the information. The central and south-eastern Kimberley remains largely unexamined, as do the vast tracts of Aboriginal land along the northwest coast. Few surveys have had a systematic, quantitative design that was, or can be, repeated to detect changes through time. Their coverage of different plant and animal taxa has been selective, rather than comprehensive. Most surveys have been limited to the dry season, although many species are prevalent only in the wet. This clearly hampers our biodiversity knowledge – for example, herbarium data reveal that one in eight collections made in the wet are new species records for the Kimberley (Kevin Thiele, pers. comm.).

Consequently there are gaps in species inventory as well as in knowledge of species distribution and status. A systematic, site-based, biodiversity survey of the entire Kimberley is required to provide a context for interpreting localised datasets, guiding land management and assessing development proposals. In this context, there is an immediate need to provide a clearer understanding of the interacting effects of fire regimes, grazing and weeds as influences on the processes threatening Kimberley ecosystems (the mechanisms of change).

Better maps of vegetation, soil and environmental geology (at scales of 1:100 000 or better) are needed to provide improved resolution on patterns in biodiversity for conservation planning (McKenzie *et al.* 2003).

Key References

See Attachment 4, which is arranged under four sub-headings.

Attachment 1. Bioregional descriptions

The North Kimberley Bioregion occupies the north-western part of the Kimberley Craton and has a hot, tropical, sub-humid climate with summer rainfall. Its main landscape mosaics are rugged Proterozoic sandstone outcrop with shallow sandy soils supporting savanna woodlands of woollybutt and Darwin stringybark over hummock grasses, and Proterozoic volcanic strata with red and yellow earths supporting savanna woodland of species such as Darwin box and cabbage gum over sorghum grass. Riverine forests of paperbark and pandanus occur along drainage lines, small patches of monsoon rainforest are scattered through the savanna and extensive mangals occur in estuaries and sheltered embayments. Two subregions are recognised. The Mitchell subregion has a diverse array of exposed basement strata dissected by rivers, and a rugged sunken coastline, deeply embayed. Skeletal sandy soils incompletely mantle sandstone boulder country, and there are significant areas of various volcanic surfaces, as well as lateritised uplands with open forests, and alluvial floors along major river valleys. The Berkeley subregion is less dissected than the Mitchell, and dominated by an upland of mainly Pentecost sandstones more continuously mantled by (sandy) soils supporting an open savanna woodland with few rainforest patches.

The Central Kimberley Bioregion comprises hilly to mountainous country with skeletal sandy soils supporting hummock grass communities with scattered trees on parallel siliceous ranges of Proterozoic sedimentary rocks, and with earths on Proterozoic volcanics in valleys supporting ribbon grass with scattered trees. Open forests of river red gum and pandanus occur along drainage lines. Three subregions are recognised. The Pentecost subregion, the true central Kimberley, is mostly underlain by Pentecost sandstone strata, with King Leopold and Warton sandstone ranges along its southern peripheries. Large areas are mantled by Cenozoic soils and there is moderate dissection by several rivers. The Hart subregion's landscapes are dominated by dolerite, exposed where the basement is folded at the eastern edge of the Kimberley Craton. It is the driest subregion, has a rugged topography, and is the headwaters of the Ord and Fitzroy Rivers. The Mount Eliza subregion forms the south-western periphery of Kimberley Craton, and is very rugged with intense folding and exposure of basement strata.

Above In sheltered embayments and creek systems along the Kimberley coast dense stands of mangroves occur. They are often fringed on the landward side by expansive tidal mudlats.

Above left Freshwater creeks are a feature of the Kimberley landscape and are often fringed by paperbarks (*Melaleuca* spp.) and screwpines (*Pandanus* spp.) with emergent aquatics such as waterlilies (*Nymphaea violacea*) being common.

Left Tropical savanna on the foot slopes of the King Leopold Ranges in the Central Kimberley Bioregion.

Above Pindan (*Acacia*) shrubland is the dominant vegetation of the sandy plains of the Dampierland Bioregion.

The Dampierland Bioregion is the hot, semi-arid, northern edge of the Canning Basin which underlies the Great Sandy Desert. It has two distinct subregions. The Fitzroy Trough subregion contains the middle and lower catchment of the Fitzroy River, and is dominated by alluvial plains that support woodlands over perennial bunch and annual cane grass understoreys, interrupted by riverine forests of river gum and cadjeput. Devonian limestone barrier reef structures preserved along the Trough's northern and eastern edges support scattered vine thicket trees and shrubs over hummock grass. The Pindanland subregion comprises gently undulating sandplain landscapes with wooded shrublands dominated by wattles, and occasional low hills with hummock grasslands. The region's extensive coastal plains comprise mudflats that support mangal, samphire and couch grasslands fringed by low paperbark forest, as well as beach strand and coastal limestone outcrops with shrub-*Spinifex* communities.

The Victoria-Bonaparte Bioregion in Western Australia comprises Phanerozoic strata mantled by Quaternary marine plains that support extensive samphire-couch grasslands on their northern (seaward) periphery, where there are also monsoon vine thicket rainforests on coastal dunes and mangroves on tidal mudflats and waterways. The inland periphery of these plains include occasional mound springs supporting paperbark and swamp rainforests. In eastern and southern areas are red earth and black soil plains with an open savanna dominated by tall annual cane grasses associated with flood plains of the lower Ord and Keep Rivers, punctuated by abrupt ranges with incised plateaux of Proterozoic sandstone partially mantled by skeletal sandy soils that support savannas of low open trees with hummock grass understoreys. Between the western edge of the plains and Cambridge Gulf there are Devonian limestone ranges, supporting low open rainforests (monsoon vine thickets) and areas of hummock grassland.

The Ord Victoria Plains Bioregion in Western Australia is a lithological mosaic of (1) abrupt Proterozoic and Phanerozoic ranges mantled by shallow sand and loam soils supporting hummock grasslands with sparse low snappy gum and bloodwood trees, (2) Cambrian volcanics and limestones that form the extensive plains of the upper Ord River valley with short-grass on dry calcareous soils and medium-height grassland communities on cracking clays and across which riverine forests of red river gum fringe drainage lines, and (3) cracking clay plains and lateritised upland sand plains with sparse trees on Phanerozoic strata. The first two form the Ord Subregion, and are drained northwards by the Ord River. The third, in the south, is known as the Kimberley Interzone Subregion. A gently undulating, elevated erosional plain, it is drained southward into the desert by Sturt and Wolfe Creeks, and separated from the dissected valley of the Ord River by steep breakaways. The plateau is covered by cracking clay plains developed over volcanics, although large areas a covered by thick laterite covered by extensive desert sandplains. The climate is dry hot tropical, semi-arid with summer rainfall.

Attachment 2. Known special landscapes, ecosystems and species

(modified from May and McKenzie 2003)

North Kimberley

- A drowned coastline with extensive coastal archipelagos from the Buccaneer Archipelago to Sir Graham Moore Island that form a virtually feral- and weed-free microcosm of the Mitchell Subregion and present an opportunity to protect intact ecosystems. In particular Augustus Island (17 952 ha) and Bigge Island (17 190 ha) are large, near-coastal, uninhabited islands with no known feral animals and a diverse intact terrestrial fauna.
- Off-shore islands such as Pelican, Troughton, Sterna, Browse, Bedwell (Rowley Shoals), Booby, Lacepede Islands, and Adele for turtle nesting, migrating shorebirds and seabird breeding.
- Mound springs and swamp rainforest.
- There is tropical laterite flora. In particular the *Livistona eastonii* palm community of the Mitchell Plateau, a palm dominated landscape, is unique in Western Australia.
- The flora and fauna of north-western margin appears to be still intact. Critical weight range mammal fauna persist in this region, such as golden bandicoot, scaly-tailed possum, monjon, nabarlek, golden-backed tree-rat and Kimberley rock-rat. None of the region's original mammals are regionally extinct yet, or are known to have disappeared from more than half of their former ranges across the region.
- The Cape Bougainville rainforest on laterite and volcanics has no hoofed feral animals and is the largest single patch of rainforest in the Kimberley.
- Airfield Swamp on the Mitchell Plateau is a large perched paperbark forest wetland.
- The Prince Regent Lineament encompassing the Prince Regent River.
- There are many endemic invertebrates, vertebrates and plants. Vertebrate species include scaly-tailed possum, monjon, black grasswren, three blindsnakes, grey whipsnake, rough-scaled python, four dragon lizards, seven geckos, 10 skinks and five frogs. Camaenid land snails have a large number of endemic species, and some endemic genera show strongly localised patterns of endemism. All the rainforest patches studied to date have endemic earthworm species associated with them. Endemic plants include *Cycas basaltica* and *Cycas lane-poolei*, *Acacia kenneallyi, Acacia smeringa, Gossypium londonderriense, Grevillea cravenii, Grevillea donaldiana, Grevillea maherae, Grevillea microstyla, Hibiscus peralbus, Typhonium peltandroides, Auranticarpa resinosa* and *Hibbertia ledifolia.*
- Sandstone ecosystems include areas of high species and ecosystem diversity and endemism. Rugged sandstone environments can provide fire protection to obligate seeders which are amongst the most vulnerable savanna plants Regeneration is by seed only and soil seed stores can be eliminated by successive fires.
- Mangroves, riparian forests and rainforest patches are resource centres for distinct faunas, including wide-ranging vagile species that dependent on the archipelago of patches, e.g. rainbow pittas, fruit pigeons, and flying foxes. They also provide dry season refuges for a variety of savanna animals, and have numerous endemic species. Laterite rainforests are of particular interest.
- Significant wetlands include the Mitchell River System, Prince Regent River System, Yampi Peninsula #WA115, Walcott Inlet System including Munja Lagoon and the lower reaches of the Isdell and the Charnley Rivers, and Airfield Swamp and Glauerts Lagoon on Mitchell Plateau.

Central Kimberley

- One permanent freshwater lake (Gladstone Lake) is listed as nationally important for the maintenance of ecological processes, migratory species, and as a drought refuge, breeding and feeding ground for a diversity of taxa.
- Numerous endemic camaenid land snails show strongly localised patterns of endemism. All the rainforest patches studied to date have endemic earthworm species associated with them.
- 'Dry' rainforest patches are resource centres for a discrete fauna, including wide-ranging vagile species that depend on the archipelago of patches, e.g. rainbow pittas, fruit pigeons and flying foxes. They also provide dry season refuges for a variety of savanna animals and plants that are obligate seeders.

- Sandstone ecosystems include areas of high species and ecosystem diversity and endemism. Rugged sandstone and dolerite environments can provide fire protection.
- Riverine ecosystems support a distinctive fauna and provide dry season refuges for a variety of savanna animals.
- Declared rare flora (*Eucalyptus mooreana*) on the mountain summits of the King Leopold Ranges.
- Preserved Devonian landscapes of the Yampi Peninsula.

Dampierland

- Stranded remnants of a Devonian barrier reef system with Windjana and Geikie Gorges, Mimbi Caves and Tunnel Creek. The gorges are world-class tourist destinations and Tunnel Creek, which passes through the Napier range via a cave, supports colonies of the endemic Yellow-lipped Cave Bat and two monotypic genera endemic to Australia (Ghost Bat and Orange Horseshoe Bat).
- Off-shore islands (Lacepedes) for turtles and seabird colonies (Burbidge's Island paper).
- Rainforests and paperbark swamps associated with the organic profiles of mound springs on coastal mudflats and palaeorivers, and with primary coastal sand dunes on Dampier Peninsula.
- Camballin Floodplain is one of only two large riverine floodplains in the Kimberley.
- Also significant are the palaeoriver systems at Roebuck Bay and along the Eighty Mile Beach, where vast grasslands occur on wetland plains, and enormous numbers of migratory wading birds rely on extensive coastal mudflat systems.
- Mandora wetlands, with its mound springs, and where Halse recorded more than 5000 breeding waterbirds.
- *Keraudrenia exastia* and *Pandanus spiralis* var. *flammeus* are both declared rare species.

Victoria-Bonaparte

- Extensive mangrove community of the False Mouths of the Ord, including WA's only known Black Butcherbird population.
- Ramsar Convention wetlands on the Ord River floodplains and the man-made Lake Kununurra.
- Cambridge Gulf and its associated river systems and saltwater crocodile population.
- Black and red-soil communities of the Ord and Keep River floodplains.
- Stranded Devonian palaeo-reef system of the Ningbing Range with its peculiar vine thicket communities and strongly localised, endemic species and genera of land snails.
- Extensive Arafura Coastal Plain with its salt flat, grasslands, coastal creeks, sand dune rainforests and mound spring rainforests.
- Isolated spring and gorge rainforests associated with sandstone ranges that have endemic land snail and earthworm species and, along with riverine rainforests, act as refugia for a variety of otherwise sub-humid plants and vertebrates including Green-backed Gerigone, fruit pigeons and flying foxes.
- Major flatback turtle rookery at Cape Domett.
- Gorge network incising the plateau of the Cockburn Range.
- Adolphus, Pelican and Lacrosse islands in Cambridge Gulf.

Ord Victoria Plains

- Structure of the Bungle Bungle Range and its several endemics species (e.g. Woinarski 1992) and outlying populations of otherwise arid zone species, e.g. *Pseudomys desertor.*
- Rainforest patches associated with springs in ranges such as the Osmond Range, with their endemic land snails and earthworm species that provide dry season refuges for species such as fruit pigeons and flying foxes (McKenzie *et al.* 1991).
- The enormous man-made Lake Argyle with its extensive riparian zone (e.g. Kitchener 1978).
- Riverine forests acting as dry season refuges and corridors (Woinarski *et al.* 2000).
- Lake Gregory on a variety of Ramsar criteria, including abundant water birds and aquatic invertebrates (Halse *et al.* 1998a and b).
- Vast tracts of grassland on cracking clay soil plains in the eastern parts of the region, although their biota is poorly documented.

Attachment 3. Overall condition and trend of Kimberley bioregions

North Kimberley: There is a continuing general deterioration in the condition of the bioregion's main savanna ecosystems, rainforests and riverine forests, mainly due to fire and grazing (e.g. Vigilante and Bowman 2004a and b). Most of the important wetlands recognised (river systems, riverine floodplains, swamp rainforests, freshwater lakes and swamps) are in good condition, but deteriorating. The primary threatening processes for all these wetlands are changed fire regimes, grazing pressure from feral herbivores and changed hydrology. An investigation of the current status of individual species and ecosystems is urgent, along with research to build a better understanding of the impact of threatening processes and management opportunities (Graham and McKenzie 2004). A range of vegetation associations and 'at risk' ecosystems need to be reserved, and 44 of the region's plant, five mammal, three bird and six reptile species are considered to be rare or threatened, mainly due to changed fire regimes operating at the landscape scale (Gordon and McKenzie 2004). Although no feral vertebrates have colonised the coastal islands, and they are virtually weed-free, hot dry-season fires are becoming increasingly frequent.

Cascade Creek in the Prince Regent River Nature Reserve. Photo – David Bettini

Central Kimberley: The effects of late dry-season fires, feral animals and stock are equally evident in all three subregions, and substantial changes to vegetation structure are ubiquitous. The trend is for a continued decline, although it is fox and rabbit free and essentially uninhabited. Most of the region has a long history of pastoral use, with introduction of grass species for pasture improvement, and application of fire to create 'green-pick' late in the dry season. Gladstone Lake is not in pristine condition and declining because of grazing pressure from cattle. Riparian zones throughout the region are also declining in condition because of the independent or conjoint effects of changed fire regimes, grazing pressure from feral herbivores, weeds and changed hydrology in the catchments (e.g. Ludwig *et al.* 2005) as a result of decreasing perennial vegetation cover and loss of top soil. 23% of the region's original non-volant mammal fauna is known to be either regionally extinct or has disappeared from more than half of its former range across the region (McKenzie and Burbidge 2002). Research being carried out by AWC at their Mornington property is showing that good fire management is possible, and that this leads to fauna recovery (Legge *et al.* 2008).

Dampierland: The structure, density and composition of perennial vegetation throughout the region has declined. Twenty ecosystems are thought to be at risk, including rainforest, riverine forest, woodlands, pindan, mangroves, grasslands, herbland, sedgeland and rushland, and freshwater lakes. There is not enough information available to identify trends in their condition, although five are definitely in decline. Main threatening processes include changed fire regimes, grazing pressure and weeds. Several are threatened by human disturbance and changed hydrology. Most rivers, wetlands and claypans are in a fair or good condition, but declining, because of grazing and trampling by stock, tourist-use, siltation and altered flows, feral animals, changed fire regimes and, at two wetland sites, impacts due to their proximity to Broome. The lower Fitzroy is in poor condition; weeds such as noogoora burr dominate the understorey and large tracks of passion vine and some rubbervine occur in the riparian canopy. 45% of the region's original non-volant mammal fauna is now regionally extinct or has disappeared from more than half of its former range across the region. Two plant, 5 mammal, 2 bird and 5 reptile species are listed as threatened or vulnerable; the threatening processes are poorly understood or unknown in most cases, but thought to be changed fire regimes and grazing pressure operating at the landscape scale.

Ord Victoria Plains: A century of grazing pressure has led to massive degredation of alluvial surfaces and riverine vegetation, both denudation of vegetation and extremely deep sheet and gully erosion across the entire Ord Subregion (e.g. Sandercock 2004). Although large tracts of pastoral properties were compulsorially destocked, recovery has been gradual and weeds such as birdwood and buffel grass now dominate many of the region's ecosystems. Flood events are more severe as a result of higher velocity and volume of run-off from the savanna during rain-events stripping riverine vegetation, depositing enormous sandy bedloads in the upper and middle sections of the Ord River System that have occluding river pools, and depositing enormous banks of fine-textured sediment up to 20 metres deep in the lower Ord (e.g. Warman 1999, Wolanski *et al.* 2001, Sandercock 2004, Start and Handasyde 2002). Impoundments associated with the Ord Irrigation Area have drastically altered river flows, leading to major changes in riverine vegetation (Froend 2000, Ruprecht 2000) and loss of species such as the Purple-crowned Wren and Black Bittern. Riparian systems have attracted many serious weed infestations including noogoora burr, bellyache bush and castor oil plant, and large densities of feral donkeys and cattle have degraded the valley and slope surfaces of the Ord Subregion. As a result of the changes fire regimes exacerbated by grazing pressure, perennial grasses, shrubs and trees are far less prominent in savanna ecosystems across the region's landscapes, both the plains and uplands, and the simplified vegetation that now remains, is dominated by a small suite of annual grasses. Twenty-six percent of the region's original non-volant mammal fauna is now either regionally extinct or has disappeared from more than half of its former range across the region. This savanna simplification has create late-dry season resource gaps for granivorous vertebrates, such as the endangered Gouldian Finch (Franklin 1999).

Victoria-Bonaparte: The CRC for Tropical Savannas has systematically reviewed the environmental characteristics of the Ord River's riparian zone from the top of the catchment to the Cambridge Gulf (A.N. Start, pers. comm.). The impacts of water impoundment and flow control on the lower Ord River have been assessed by Froend (2000), Halse (2000), Loh *et al.* (2001), Ruprecht (2000), Semeniuk (2000), Start (2000) and Wyrwoll (2000). On-going changes to the status of fauna (particularly mammals) and flora are apparent, including continuing simplification of assemblages at the landscape level which are affecting vegetation structure (eg. loss of shrub layer), composition (eg perennial vs. annual grasses), vegetation cover, leaf litter, and soil organic-A horizons. Eighteen percent of the region's original non-volant mammal fauna is now either regionally extinct or has disappeared from more than half of its former range across the region.

Attachment 4: References cited in this document

Part A: Marine references

- Beasley I, Robertson KM, Arnold P (2005). Description of a new dolphin, the Australian Snubfin Dolphin, *Orcaella heinsohni* sp. nov.. (Cetacean, Delphinidae). *Marine Mammal Science* 21(3): 365-400.
- Berry PF (1986). Faunal surveys of the Rowley Shoals, Scott Reef and Seringapatam Reef, northwesten Australia. *Records of the Western Australian Museum*, Supplement No.25, 1986. 106pp
- CALM (2003). Information Sheet on Ramsar Wetlands. Report to the Ramsar Convention Bureau by the Department of Conservation and Land Management, Perth, WA. November 2003
- Cresswell GR and Badcock KA (2000). Tidal mixing near the Kimberley coast of NW Australia. *Mar. Freshwater Res*. 51:641-646
- Department of Environment and Conservation (2008). Preliminary reconnaissance survey of benthic habitats in the Anjo Peninsula area, Kimberley Bioregion, Western Australia. Report to the Northern Development Taskforce, Department of Industry and Resources. Department of Environment and Conservation, Perth, WA, October 2008
- Department of the Environment, Water Heritage and the Arts (2008). The North-west Marine Bioregional Plan: Bioregional Profile, a description of the ecosystems, conservation values and uses of the north-west marine region. http://www.environment.gov.au/coasts/mbp/north-west/
- Fletcher WJ and Santoro K (eds) (2007). *State of the Fisheries Report 2006/07*. Department of Fisheries, Western Australia
- Fletcher W and Head F (2006). *State of the Fisheries Report 2005-06.* Department of Fisheries, Government of Western Australia, Perth, Western Australia
- Fry G, Heyward A, Wassenberg T, Taranto T, Stiegliz T and Colquhoun J (2008). Benthic Habitat surveys of potential LNG hub locations in the Kimberley region. A CSIRO and AIMS Joint Preliminary Report for the Western Australian Marine Science Institution, 18 July 2008.
- Halpern BS *et al.* (2008). A global map of human impact on marine ecosystems. *Science* 319: 948-952
- Holley, DK and Prince RIT (2008). Historical datasets of dugong (*Dugong dugong*) observations in the Kimberley region of Western Australia. Data Report No. 2008-03 Coastal and Marine Ecosystems Research, Edith Cowan University, Joodalup, WA. 24pp
- INPEX (2008). Presentation at the Northern Development Taskforce Site Evaluation Workshop. Broome, WA, 24 July 2008.
- IUCN Working Group on Mangrove Ecosystems (1981). *First report on the global status of mangrove ecosystems.* Toowong, Qld.
- Jenner C and Jenner M (2008). Whale and dolphin management issues in Western Australia. Presentation at the Northern Development Taskforce site evaluation workshop, Broome, WA, 24 July 2008.
- Kuo J (2000). Taxonomic notes on *Halophila minor* and *H. ovata. Biol. Mar. Medit* 7(2): 79-82
- Loneragan N, Die D, Kenyon R, Taylor B, Vance D, Manson F, Pendrey, B and Venables W (2002). The growth, mortality, movements and nursery habitats of red-legged banana prawns (*Penaeus indicus*) in the Joseph Bonaparte Gulf: Final Report to the FRDC (FRDC Project 97/105). FRDC Report. Fisheries Research Development Corporation. PO. Box 222 Deakin West, ACT, 2600.
- Long SC and Holmes TH (2009). Comparative marine biodiversity of the Rowley Shoals 2007: Benthic assemblages data report. Marine Science Program Data Report Series: MSPDR7. January 2009. Marine Science Program, Department of Environment and Conservation, Perth, Western Australia. 59pp.
- Marine Parks and Reserves Selection Working Group (1994). *A representative marine reserve system for Western Australia.* Report of the Marine Parks and Reserves Selection Working Group. Department of Conservation and Land Management, Perth, WA. June 2004.
- McFarlane G (2008). Cable Beach Community-based Monitoring Program – Broome, Western Australia: Report of nesting activity for the flatback (*Natator depressus*) marine sea turtle 2006-07 and 2007-08. *Conservation Volunteers Australia, December 2008*

- McKenzie L (2007). Seagrass-Watch: Proceedings of a workshop for monitoring seagrass habitats in the Kimberley Region, Western Australia. Broome, WA, September 2007.
- Newman SJ, Young GC, Potter IC (2004). Characterisation of the inshore fish assemblages of the Pilbara and Kimberley coasts. FRDC Project Report. (Project 2000/132). Department of Fisheries, Research Division. North Beach, WA.
- Pendretti YM, and Paling EI (2000). WA Mangrove Assessment Project: 1999-2000. Report prepared by Murdoch University. http://wamangrove.murdoch.edu.au
- Piersma T, Pearson, G, Hickey R, Dittmann S, Rogers D, Folmer E, Honkoop P, Drent, J, de Goeij P and Marsh L (2006). Roebuck Bay Invertebrate and Bird Mapping 2006. Research Report ROEBIM-06. June/ July 2006
- Piersma T, Pearson G, Hickey R and Lavaleye M (Eds) (1999). The long mud: Benthos and shorebirds of the foreshore of Eighty-mile Beach, Western Australia. Report on the 'Anna Plains Benthic Invertebrate and bird Mapping 1999' (ANNABIM-99). http://www.nioz.nl/public/nioz_reports/nioz-report_2005-2.pdf
- Prince RIT (1986). Dugong in northern waters of Western Australia 1984. Technical Report No.7, Department of Conservation and Land Management, Perth, WA, 38pp
- Smith L, Gilmour J and Heyward A (in prep.). System-wide decline in coral abundance and recruitment following a catastrophic bleaching event.
- Smith L, McAllister F, Rees M, Colquhoun J and Gilmour J (2006). Benthic Habitat survey of Scott Reef (0 – 60 m). Report to Browse Joint Venture Partners by the Australian Institute of Marine Science. September 2006.
- WA Museum (2008). Intertidal habitats of selected sites in the Canning Bioregion: preliminary field results. Report to the Northern Development Taskforce by the Western Australian Museum, Perth, WA, May – June 2008. 77pp
- Waples K (2007). Kimberley Biodiversity Review. Report prepared for the EPA Services Unit and the Environmental Management Branch, Department of Environment and Conservation, WA
- Walker DI (1995). Seagrasses and Macroalgae. In Wells, F.E., Hanley R. and Walker, D.I. (Eds) *Marine Biological survey of the southern Kimberley, Western Australia.* Western Australian Museum, Perth, W.A. 1995
- Walker DI (1997). Marine Biological survey of the central Kimberley coast, Western Australia. University of Western Australia, Crawley, W.A. 1997
- Walker DI, Wells FE and Hanley R (1996). Survey of the marine biota of the eastern Kimberley, Western Australia. University of Western Australia, Western Australian Museum and the Museum and Art Gallery of the Northern Territory. 1996.
- Walker DI and Prince, RIT (1987). Distribution and biogeography of seagrass species on the northwest coast of Australia. *Aquatic Botany* 29: 19-32
- Wells FE, Hanley R and Walker DI (1995). Marine Biological survey of the southern Kimberley, Western Australia. Western Australian Museum, Perth, W.A. 1995
- Wood M and Mills D (2008). A turning of the tide: science for decisions in the Kimberley-Browse marine region. A report prepared for the Western Australian Marine Science Institution (WAMSI). August 2008

Part B: Terrestrial references

Overviews

- EPA 2007. State of the environment report: Western Australia 2007. Department of Environment and Conservation, Perth, Western Australia.
- Environment Australia (2001). A Directory of Important Wetlands in Australia. Third Edition. Environment Australia, Canberra.
- Goudie AS, Sands MJS (1988). Kimberley, Australia, 200: the geomorphology and biology of the Kimberley Region, north-western Australia : a preliminary bibliography. Royal Botanic Gardens, Kew. 23 leaves.
- Graham G, McKenzie NL (2003). A conservation case study of Western Australia's Mitchell subregion (North Kimberley 1) in 2003. Department of Conservation and Land Management. 56 pp.
- Handasyde T (2005). Report on compilation of Kimberley biodiversity and natural resource management data and associated information. Kimberley Regional Fire Management Project, Natural Heritage Trust.
- Halse SA, Scanlon MD and Cocking JS (2001). First national assessment of river health: Western Australian program. Milestone report 5 and final report. Department of Conservation and Land Management, Western Australia.
- May JE and McKenzie NL (2003). A biodiversity audit of Western Australia's 53 biogeographical subregions in 2002. Department of Conservation and Land Management, Perth.
- McKenzie NL, Johnston RB, Kendrick PG (1991). Kimberley rainforests of Australia. Surrey Beatty and Sons, Chipping Norton, NSW.
- McKenzie NL and Burbidge AA (2002). Mammals. *In:* Australian terrestrial biodiversity audit 2002. National Land and Water Resources Audit. 2002, Commonwealth Government, Canberra.
- McKenzie NL, May JE, McKenna S (2003). Bioregional summary of the 2002 Biodiversity audit for Western Australia. Department of Conservation and Land Management, Perth.
- Pedretti YM, Paling, EI (2001). WA mangrove assessment project 1999-2000. Murdoch University, Perth.
- Vigilante T (2006). Saltwater Country Project: database of natural and cultural values for the North Kimberley coast. Natural Heritage Trust Saltwater Country Project. Final report to the Rangelands NRM Coordinating Group.
- Waples K (2007). Kimberley biodiversity review. Unpublished draft report. Department of Environment and Conservation, Western Australia.
- Wheeler JR, Rye BL, Koch BL and Wilson AJG, (1992). *Flora of the Kimberley Region.* Western Australian Herbarium, Como.

Surveys

- Barrett RL, Start AN (2001). Flora of the Yampi Sound Defence Training Area. Report to Australian Heritage Commission. Botanic Gardens and Parks Authority. Perth.
- Beard JS (1979). Vegetation survey of Western Australia: Kimberley. University of Western Australia Press, Perth.
- Bradley AJ, Kemper CM, Humphreys WF, How RA (1987). Small mammals of the Mitchell Plateau region, Kimberley, Western Australia. *Australian Wildlife Research* 14, 397-414.
- Burbidge AA and McKenzie NL (1978). The islands of the North-west Kimberley, Western Australia. *Wildlife Research Bulletin* No. 7. Department of Fisheries and Wildlife, Perth.
- Burbidge AA, Fuller PJ, Lane JAK and Moore SA (1987). Counts of nesting boobies and Lesser Frigate-birds in Western Australia. *Emu* 87, 128-129.
- Chapman A (1993). Mammals of the Munja-Walcott Inlet area, West Kimberley, Western Australia. *Western Australian Naturalist*, 19, 140-146.
- Cho J-L, Park J-G, and Humphreys WF (2005). A new genus and six new species of the Parabathynellidae (Bathynellacea, Syncarida) from the Kimberley Region, Western Australia. *Journal of Natural History* 39, 2225-2255.

- Collins, P. (1995). The birds of Broome: an annotated list. Broome Bird Observatory for Australasian Ornithologists Union, Broome. 84pp.
- Ecologia Environment (2004). Beagle Bay "Big Tree Country" Timber Plantation: Fauna Assessment Survey. Unpublished Report for Tropical Timber Plantations Pty Ltd.
- Fitzgerald K, Western Australia. Dept. of Agriculture, (1992). A review of the major groundwater resources in Western Australia Geological Survey of Western Australia for the Kimberley Water Resources Development Office.
- Forbes SJ, Kenneally KF and Aldrick SM (1988). A botanical survey of Vansittart Bay and Napier Broome Bay, north Kimberley, Western Australia. *Western Australian Naturalist,* 17, 129-200.
- Gellatly DC and Sofoulis, J (1973). Yampi, Western Australia 1:250,000 Geological Series, explanatory notes. Australian Government Publishing Service, Canberra.
- Graham G (1994). A Biological Survey of the Cockburn Ranges. February – April 1994. Department of Conservation and Land Management. Unpublished report.
- Graham G (1992). A biological survey of the Silent Grove area (Mt Hart Station) Kimberley Region. Department of Conservation and Land Management.
- Halse S, Shiel RJ and Williams WD (1998a). Aquatic invertebrates of Lake Gregory, northwestern Australia, in relation to salinity and ionic composition. *Hydrobiologica* 381, 15-29.
- Halse S, Pearson GB and Kay WR (1998b). Arid zone networks in time and space: waterbird use of Lake Gregory in north-western Australia. *International Journal of Ecology and Environmental Sciences* 24, 207-222.
- Halse S (2000). Waterbirds and invertebrates. pp 100-106, In: Anon 2000. *Recommendations for estimation of interim ecological water requirements for the Ord River.* Ord River Scientific Panel report to the Water and Rivers Commission. Water and Rivers Commission, Perth.
- Hanley JR (1998). Flora and fauna of the Fitzroy estuary: characteristics and requirements. Limnology, Edith Cowan University, Claremont Campus, Western Australia,
- Hickey, R., Pearson, G., Piersma, T. 2003. Maps, mud and birds. *Geospatial Solutions* 13, 40-43.
- How R, Schmitt L, Teale R and Cowan M (2006). Appraising vertebrate diversity on Bonaparte islands, Kimberley, Western Australia. *Western Australian Naturalist* 25, 92-110.
- Humphreys WF (1995). Limestone of the east Kimberley, Western Australia – karst and cave fauna. Unpublished Report to the Australian Heritage Commission and the Western Australian Heritage Committee.
- Humphreys WF (1999). Groundwater fauna sampling in the Kimberley north of 16° S and east of 128°E. A report for Kinhill Pty Ltd pertaining to Stage 2 (M2): Ord River Irrigation Area project.
- Humphreys WF (2003). Report on 2003. Stygofauna sampling at the Argyle Diamond Mine, Kimberley, Western Australia. Unpublished report to Argyle Diamond Mines Pty Ltd, Western Australian Museum.
- Johnstone RE (1990). Mangroves and mangrove birds of Western Australia. Western Australian Museum, Perth.
- Kabay ED, Burbidge AA (1977). A Biological Survey of the Drysdale River National Park, North Kimberley, WA in 1975. *Wildlife Research Bulletin*, Western Australia. No. 6. Department of Fisheries and Wildlife, Perth.
- Keighery GJ (1999). Weed surveys in the Kimberley. *Boab Bulletin* 35, 3-4.
- Keighery GJ, Gibson N, Kenneally KF (1995). Biological Inventory of Koolan Island. 1 flora and vegetation. *Records of the WA Museum* 17, 237-248.
- Kenneally K, Coate K, Gueho R, Grosse D (1994). Wildlife and wilderness of the east Kimberley: expedition report. Department of Conservation and Land management. Landscope Expeditions 5. 8.
- Kenneally K, Coate K (1994). Birds and botany of the north Kimberley, Landscope Expedition report. Department of Conservation and Land Management.
- Kenneally KF, Edinger DC (1993). A botanical survey of Walcott Inlet, Kimberley, Western Australia. *Western Australian Naturalist* 19, 84-99 .

- Kenneally KF (1972). Kimberley Islands expedition. *Swans.* 3. 31-32.
- Kitchener DJ (1978). Mammals of the Ord River area, Western Australia. *Records of the Western Australian Museum* 6, 189-219.
- McKenzie NL (1981). Wildlife of the Edgar Ranges area, south-west Kimberley, Western Australia. Wildlife Research Bulletin, Western Australia No. 10. Department of Fisheries and Wildlife, Perth.
- McKenzie NL (1983). Wildlife of the Dampier Peninsula, South-west Kimberley, Western Australia. *Wildlife Research Bulletin*, Western Australia. No. 11. Department of Fisheries and Wildlife, Perth.
- McKenzie NL and Rolfe JK (1986). Structure of bat guilds in the Kimberley mangroves, Australia. *Journal of Animal Ecology* 55, 401-420.
- McKenzie NL, Fontanini L, Lindus NV, Williams MR (1995). Biological inventory of Koolan Island, WA: Zoological notes. *Records of the Western Australian Museum* 17, 249-266.
- Messel H, Burbidge AA, Fuller PJ (1987). Tidal waterways of the Kimberley surveyed during 1977, 1978 and 1986 Surveys of tidal waterways in the Kimberley region, Western Australia and their crocodile populations: monograph. 357 pp.
- Miles JM and Burbidge AA (1975). A biological survey of the Prince Regent River Reserve, Northwest Kimberley, Western Australia. *Wildlife Research Bulletin*, Western Australia No. 3. Department of Fisheries and Wildlife, Perth.
- Morgan DL, Allen MG, Bedford P, Horstman M (2004). Fish fauna of the Fitzroy River in the Kimberley region of Western Australia including the Bunuba, Gooniyandi, Ngarinyin, Nyikina and Walmajarri names. *Records of the Western Australian Museum*. 22, 147-161.
- Palmer C (2001). Kimberley Regional Fire Management Project: Beagle Bay Wildlife Survey. Department of Conservation and Land Management, Kununurra, WA. Unpublished dataset.
- Palmer C (2002). Kimberley Regional Fire Management Project: Yampi 1 (Rock) Wildlife Survey. Department of Conservation and Land Management, Kununurra, WA. Unpublished dataset.
- Palmer C (2002). Kimberley Regional Fire Management Project: Yampi 2 (Eucalypt) Wildlife Survey. Department of Conservation and Land Management, Kununurra, WA. Unpublished dataset.
- Rogers DI, Piersma T, Lavaleye M, Pearson GB and de Goeij P (2003). *Life along land's edge. Wildlife on the shores of Roebuck Bay, Broome.* Department of Conservation and Land Management, Kensington.
- Saenger P (1998). Mangrove vegetation – an evolutionary perspective. *Marine and Freshwater Research* 49, 277-286.
- Semeniuk V, Kenneally KF and Wilson PG (1978). *Mangroves of Western Australia*. Western Australian Naturalists' Club, Perth.
- Semeniuk V (1980). Quaternary stratigraphy of tidal flats, King Sound, Western Ausralia. *J. Roy. Soc. WA* 63, 65-78.
- Semeniuk V (1982). Geomorphology and Holocene history of the tidal flats, King Sound, Western Australia. *J. Roy. Soc. WA* 65, 47-68.
- Semeniuk V (1985). Development of mangrove habitats along ria shorelines in north and north-western tropical Australia. *Vegetatio* 60, 3-23.
- Sawle M (1988). A survey of rare and uncommon mammals in the Kimberley region of Western Australia, May-July 1988. Murdoch, WA. 57pp.
- Smith M (1998). The Monitoring River Health Initiative and aquatic macroinvertebrates in the Kimberley region of Western Australia. Limnology of the Fitzroy River, Western Australia: a technical workshop, 11-12pp.
- Solem A (1988). Maximum in the minimum: biogeography of land snails from the Ningbing Ranges and Jeremiah Hills, northeast Kimberley, Western Australia. *J. Malac. Soc. Aust.* 9, 59-113.
- Speck NH *et al.* (1960). The Lands and Pastoral Resources of the North Kimberley Area, W.A. CSIRO *Aust. Land Res. Ser.* No. 4, Melbourne.
- Speck NH *et al.* (1964). General Report on the Lands of the West Kimberley Area, W.A. CSIRO *Aust. Land Res.* Ser. No. 9, Melbourne.

- Stewart GA *et al.* (1970). Lands of the Ord-Victoria Area, Western Australia and Northern Territory. CSIRO *Aust. Land Res.* Ser. No. 28, Melbourne.
- Storr, G.M. (1980). Birds of the Kimberley division, Western Australia. Special Publication No. 11. Western Australian Museum, Perth.
- Thom BG, Wright LD, Coleman JM (1975). Mangrove ecology and deltaic-estuarine geomorphology: Cambridge Gulf-Ord River, Western Australia. *Journal of Ecology* 63, 203-232.
- Tulp, I. and de Goeij, P. (1991). Hot news from a hot place: feeding ecology studies on knots and other waders in Broome, Northwest Australia. *Stilt* 19, 24-26.
- Tyler I (1997). Geology and landforms of the Kimberley. *Landscope* 12, 16-21.
- Watkins, D. (1993). Roebuck Bay: Background information for the conservation of a wetland of international importance. Department of Conservation and Land Management, Perth.
- Wells FE and Bryce CW (1996). Molluscs. pp 54-55, *In:* Walker DI, Wells FE, Hanley JR (eds) Marine Biological Survey of the Eastern Kimberley, Western Australia. University of Western Australia, Nedlands.
- Western Australian Museum, Field Museum of Natural History (1981). *Biological Survey of Mitchell Plateau and Admiralty Gulf, Kimberley, Western Australia:* papers resulting from a joint field expedition by the Western Australian Museum and the Field Museum of Natural History, Chicago, 1976-1977. Western Australian Museum, Perth.
- Willing T, Dureau D (2000). Botanical survey for proposed Tropical Timber Plantation, Beagle Bay, West Kimberley, WA. Conservation and Land Management, Broome
- Willing T (2000). Kimberley Coast: Cape Domett to King George River botany survey report: 18-21 February 2000. Department of Conservation and Land Management.
- Willing T (2001). Ashmore Reef and Kimberley offshore Islands botany survey report: 22-25 February 2001. Department of Conservation and Land Management.
- Wilson GDF, and Keable SJ (1999). A new genus of phreatoicidean isopod (Crustacea) from the North Kimberley Region, Western Australia. *Zoological Journal of the Linnean Society, London* 126, 51-79.
- Wilson GDF and Ponder WF (1992). Extraordinary new subterranean isopods (Peracarida: Crustacea) from the Kimberley Region, Western Australia. *Records of the Australian Museum* 44, 279-298.
- Woinarski, J.C.Z. (1992). Biogeography and conservation of reptiles, mammals and birds across north-western Australia: an inventory and base for planning an ecological reserve system. *Wildlife Research* 19, 665-705.
- Woinarski J, Menkhorst K, Gambold N and Braithwaite R (1992). Mammals of the Bungle Bungle area. pp. 53-67. In *A survey of the wildlife and vegetation of Purnululu (Bungle Bungle) National Park and adjacent area* ed by JCZ Woinarski. Research Bulletin No. 6. Department of Conservation and Land Management: Perth.
- Woinarski JCZ, Brock C, Armstrong M, Hempel C, Cheal D and Brennan K (2000). Bird distribution in riparian vegetation in the extensive natural landscape of Australia's tropical savanna: a broad-scale survey and analysis of distributional database. *Journal of Biogeography* 27, 843-868.

Reserve recommendations

- Burbidge, AA, McKenzie, NL, Kenneally, KF (1991). Nature conservation reserves in the Kimberley, Western Australia Department of Conservation and Land Management. 164pp.
- Environmental Protection Agency (1981). Conservation reserves for Western Australia: System 7. Dept. of Conservation and Land Management.
- McKenzie, NL and Belbin L (1991). Kimberley rainforest communities: reserve recommendations and management considerations. *In* Kimberley Rainforests of Australia, Eds McKenzie, Johnston, Kendrick. Surrey Beatty and Sons, NSW.

Landscape processes

- Braithwaite RW and Muller WJ (1997). Rainfall, groundwater and refuges: predicting extinctions of Australian tropical mammal species. *Australian Journal of Ecology* 22: 57-67.
- Bridgewater PB, Cresswell ID (1999). Biogeography of mangrove and saltmarsh vegetation: implications for conservation and management in Australia. *Mangroves and Salt Marshes* 3, 117-125.
- Burrows ND (2005). Active adaptive management: enhancing the integration of science and management to improve delivery of conservation outcomes. Unpublished Report, Department of Conservation and Land Management Library.
- Craig AB (1997). A review of information on the effects of fire in relation to the management of rangelands in the Kimberley high-rainfall zone. *Tropical Grasslands.* 31, 161-187.
- Craig AB (1999). Fire management of rangelands in the Kimberley low-rainfall zone: a review. *Rangelands Journal* 21, 39-70.
- Davies PM (2000). The importance of flow on ecological processes in the Ord River, Western Australia. pp 107-111, In: Anon 2000. *Recommendations for estimation of interim ecological water requirements for the Ord River.* Ord River Scientific Panel report to the Water and Rivers Commission. Water and Rivers Commission, Perth.
- Dyer R, Jacklyn P, Partridge I, Russell-Smith J and Williams D (eds) (2001). *Savanna Burning: understanding and using fire in northern Australia.* Tropical Savannas Cooperative Research Centre. Darwin.
- EPA (2005). Fire in the Kimberley and inland regions of WA. Environmental Protection Authority, Perth.
- Franklin DC (1999). Evidence of disarray amongst granivorous bird assemblages in the savannas of northern Australia, a region of sparse human settlement. *Biological Conservation* 90: 58-68.
- Froend R (2000). Lower Ord riparian vegetation. pp 58-64, In: Anon 2000. *Recommendations for estimation of interim ecological water requirements for the Ord River.* Ord River Scientific Panel report to the Water and Rivers Commission. Water and Rivers Commission, Perth.
- Hutchins JB (1995). Fishes. pp 137-153, In: Wells FE, Hanley JR, Walker DI (eds) Marine Biological Survey of the Southern Kimberley, Western Australia. Western Australian Museum, Perth.
- Legge S, Murphy S, Heathcote J, Flaxman E, Augusteyn J and Crossman M (2008). The short-term effects of an extensive and high-intensity fire on vertebrates in the tropical savannas of the central Kimberley, northern Australia. *Wildlife Research* 35, 33-43.
- Loh I, Trayler K and Rodgers S (2001). *Discussion Paper. Consideration of drought period environmental water provisions for the lower Ord River, Western Australia.* Water and Rivers Commission. Perth.
- Ludwig JA, Tongway DJ, Eager RW, Williams RJ, Cook GD (2005). Fine-scale vegetation patches decline in size and cover with increasing rainfall in Australian savannas. *Landscape Ecology* 14, 557-566.
- Ludwig JA, Wilcox BP, Breshears DD, Tongway DJ and Imerson AC (2005). Vegetation patches and runoff-erosion as interacting ecohydrological processes in semiarid landscapes. *Ecology* 86, 288-297.
- Mangglamarra G, Burbidge AA and Fuller PJ (1991). Wunambal words for rainforest and other Kimberley plants and animals. pp 413-421, In: McKenzie, NL, Johnston, RB, Kendrick, PG. (eds). Kimberley rainforests of Australia. Surrey Beatty and Sons, Chipping Norton, NSW.
- McKenzie NL and Belbin L (1991). Kimberley Rainforest communities: reserve recommendations and management considerations. pp 453-468, In: McKenzie, NL, Johnston, RB, Kendrick, PG. (eds). Kimberley rainforests of Australia. Surrey Beatty and Sons, Chipping Norton, NSW.
- McKenzie NL, Burbidge AA, Baynes A, Brereton R, Dickman CR, Gibson LA, Gordon G, Menkhorst RW, Robinson AC, Williams MR and Woinarski JCZ (2006). Analysis of factors implicated in the recent decline of Australia's mammalian fauna. *Journal of Biogeography* 34(4), 597-611.
- Radford I and Anderson A (2006). Fire regimes in the Kimberley. Internal Report, Western Australian Department of Conservation and Land Management, Perth.
- Roth CH (2004). A framework relating soil surface condition to infiltration and sediment and nutrient mobilisation in grazed rangelands of north-eastern Queensland, Australia. *Earth Surface Processes and Landforms* 29, 1093-1104.

- Ruprecht JK and Rogers SJ (1998). Hydrology of the Ord River. Water Resources Technical Series Report WRT 21. Water and Rivers Commission, Perth.
- Ruprecht JK (2000). Hydrologic impacts of river regulation on the Ord River. pp 38-42, In: Anon 2000. *Recommendations for estimation of interim ecological water requirements for the Ord River.* Ord River Scientific Panel report to the Water and Rivers Commission. Water and Rivers Commission, Perth.
- Russell-Smith J and Dunlop C (1987). The status of monsoon vine forests in the Northern Territory: a perspective. pp 227-288, In: *The Rainforest Legacy*. Special Australian Heritage Publication No. 7(1). Australian Heritage Commission, Canberra.
- Russell-Smith J and Bowman DMJS (1992). Conservation of monsoon forest isolates in the Northern Territory, Australia. *Biological Conservation* 59, 51-63.
- Russell-Smith J, Start T and Woinarski J (2001). Effects of fire in the landscape. pp 29-49, In: Dyer R, Jacklyn P, Partridge I, Russell-Smith J and Williams D (eds.) *Savanna Burning: understanding and using fire in northern Australia.* Tropical Savannas Cooperative Research Centre. Darwin.
- Russell-Smith J Ryan PG, Cheal D (2002) Fire regimes and the conservation of sandstone heath in monsoonal northern Australia: frequency, interval, patchiness. *Biological Conservation* 104, 91-106.
- Russell-Smith J, Yates CP, Edwards A, Allan GE, Cook GD, Cooke P, Craig R, Heath B, Smith R (2003). Contemporary fire regimes of northern Australia: change since Aboriginal occupancy, challenges for sustainable management. *International Journal of Wildland Fire* 12: 283-297.
- Russell-Smith J, Yates C, and Lynch B (2006). Fire regimes and soil erosion in north Australian hilly savannas. *International Journal of Wildland Fire* 15: 1-6.
- Sandercock PJ (2004). Causes and nature of river channel changes in the Upper Ord River Catchment, north-western Australia. Ph.D Thesis, Department of Geography, The University of Western Australia, Perth.
- Semeniuk V (2000). Impacts of hydrological alteration of the Ord River on mangroves in Cambridge Gulf, lower Ord River region. pp 95-99, In: Anon 2000. *Recommendations for estimation of interim ecological water requirements for the Ord River.* Ord River Scientific Panel report to the Water and Rivers Commission. Water and Rivers Commission, Perth.
- Start AN (2000). Riparian and aquatic vegetation. pp 49-57, In: Anon (Ed.). *Recommendations for estimation of interim ecological water requirements for the Ord River.* Ord River Scientific Panel report to the Water and Rivers Commission. Water and Rivers Commission, Perth.
- Start AN and Handasyde T (2002). Using photographs to document environmental change: the effects of dams on the riparian environment of the lower Ord River. *Australian Journal of Botany* 50: 465-480.
- Start AN (2003). Fire management and healthy country in the Kimberley Region, Western Australia. pp 115-120, In: Kohen, JL (ed). *Proceedings of the 2nd. Biannual Kimberley Fire Forum.* Kimberley Specialists, Kununurra, Western Australia.
- Start AN, Burbidge AA, McKenzie NL and Palmer C (2007). The status of mammals in the North Kimberley, Western Australia. *Australian Mammalogy* 29: 1-16.
- Thom BG, Wright LD and Coleman, JM (1975). Mangrove ecology and deltaic-estuarune geomorphology: Cambridge Gulf-Ord River, Western Australia. *Journal of Ecology* 63, 203-232.
- Vernes T (2006). Ord: case-study for inappropriate development and poor planning. pp 53-58, *In:* Kimberley appropriate economies roundtable forum proceedings. Edited by Hill, R. *et al.* Broome and Cairns, Environs Kimberley, Kimberley Land Council, and the Australian Conservation Foundation.
- Vigilante, T and Bowman DMJS (2004). Effects of fire history on the structure and floristic composition of woody vegetation around Kalumburu, North Kimberley, Australia: a landscape-scale natural experiment. *Australian Journal of Botany* 52: 381-404.
- Vigilante T and Bowman DMJS (2004). Effects of individual fire events on the flower production of fruit-bearing tree species, with reference to Aboriginal people's mamangement and use, at Kalumburu, North Kimberley, Australia. *Australian Journal of Botany* 52: 405-415.
- Warman CS (1999). The impact of damming on the fluvial geomorphology of the lower Ord River, Western Australia. Honours Thesis. Department of Geography, University of Western Australia. Perth.

- Wells AG (1982). Mangrove vegetation of northern Australia. pp 57-77, In: Clough, B.F. (Ed.) Mangrove Ecosystems in Australia: structure, function and management. Australian National University Press, Canberra.
- Whitehead PJ, Woinarski J, Jacklyn P, Fell D and Williams D (2000). *Defining and measuring the health of savanna landscapes: a north Australian perspective.* Cooperative Research Centre for the Sustainable Development of Tropical Savannas: Darwin.
- Williams RJ, Cook GD, Gill AM and Moore PHR (2002). Fire regime, fire intensity and tree survival in a tropical savanna in northern Australia. *Australian Journal of Ecology* 24, 50-59.
- Williams RJ, Duff GA, Bowman DMJS and Cook GD (2007). Variation in the composition and structure of tropical savannas as a function of rainfall and soil texture along a large-scale climatic gradient in the Northern Territory, Australia. *J. Biogeog.* 23, 747-756.
- Woinarski JCZ, Milne DJ and Wanganeen G (2001). Changes in mammal populations in relatively intact landscapes of Kakadu National Park, Northern Territory, Australia. *Austral Ecology* 26: 360-370.
- Woinarski JCZ, Risler J and Kean L (2004). Response of vegetation and vertebrate fauna to 23 years of fire exclusion in a tropical *Eucalyptus* open forest, Northern Territory, Australia. *Austral Ecology* 29, 156-176.
- Wolanski E, Moore K, Spagnol S, D'Adamo N and Pattiaratchi C (2001). Rapid, human-induced siltation of the macro-tidal Ord River estuary, Western Australia. *Estuarine, Coastal and Shelf Science,* 56: 1-16.
- Wyrwoll KH, (2000) Channel dynamics and sediment regime. pp 43-48, In: Anon 2000. *Recommendations for estimation of interim ecological water requirements for the Ord River.* Ord River Scientific Panel report to the Water and Rivers Commission. Water and Rivers Commission, Perth.

Darwin Woolybutt (*Eucalyptus miniata*) is one of the most widespread eucalypts across the Kimberley and Top End of Australia. Photo – Kevin Kenneally

2009224-0509-700