4 Wetland management issues

Management issues for northern Australian wetlands

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Abstract

Wetlands of northern Australia are under increasing threat due to changes in the water regime, pollution, invasive species and physical alteration. Management issues also include the continued development of tourism and recreational facilities, mining and agriculture. Whilst such problems occur the wetlands are relatively intact compared with those elsewhere in Australia. Nevertheless, active conservation management is required and priority actions and sites need attention. An overview of the major issues affecting wetlands in northern Australia is given.

1 Introduction

The ecological character of wetlands in northern Australia (the Wet-Dry tropics) has been described and the major threats or management problems identified (Arthington & Hegerl 1988, Finlayson et al 1988, 1991, Finlayson & von Oertzen 1993, Blackman et al 1993, Fleming 1993, Jaensch & Lane 1993, Jaensch 1994, Finlayson et al 1998, Storrs & Finlayson 1997). These reviews and more recent reports on specific localities (see, for example, papers in Finlayson 1995, Jonauskas 1996) have also identified major gaps in our knowledge of management issues (threats) affecting wetlands.

Comprehensive information on the extent of wetland loss and degradation in northern Australia is not available. Further, most of the information only addresses the 'apparent' reasons for wetland loss and degradation (such as weed invasion, drainage) and little attention has been directed towards the 'underlying' socio-economic and political reasons. General information on the underlying reasons for wetland loss and degradation can be found in Hollis (1992), Finlayson (1994), Hollis and Finlayson (1996), but there is little information specific to northern Australia.

Information on the apparent reasons (*sensu* Hollis 1992) for wetland loss and degradation is uneven. An overview of this information is presented below, based primarily on reviews by Storrs and Finlayson (1997) and Finlayson et al (1998). The overview is based on information obtained from the literature and from workshops held to address management and research issues (see above references). The major management issues are described under the following headings: water regime; water quality; biodiversity and conservation; sectoral and social; and restoration and creation. Given that some issues have multiple effects on wetlands they are mentioned under more than one heading.

2 Water regime

The water regime of wetlands across northern Australia is increasingly being adversely affected by human activities. These include the construction of barrages and dams, and the expansion of irrigation, agriculture and mining. Added to this is the 'wicked' problem of global climate change and sea level rise (Bayliss et al 1998). Thus, the water regimes are being altered – flows disrupted or even stopped, water diverted and stored, and released aseasonally. Effective management of the water regime entails a holistic approach that includes steps to address catchment and even inter-catchment and global influences. The water regime of a wetland should be considered as an all encompassing concept that is comprised of a complex set of processes that affect most aspects of a wetland. These include the source, amount, and spatial and temporal distribution of sediment inputs, and the distribution of the biota.

Further, the water regime is widely recognised as probably the single most important determinant for the establishment and maintenance of specific types of wetland habitats and wetland processes. Gehrke (1995) claims that '*The combined effects of river regulation pose the greatest threat to aquatic ecosystem processes…'*. Fortunately, the massive changes to water regimes, as seen in southern Australia (see, for example, Gehrke 1995) are not as common in northern Australia. Therefore, when referring to water regimes, northern Australian wetlands are comparatively undisturbed. Lake (1995), however, issues a note of caution and warns that the wetlands of northern Australia are being exposed to threats before there is even a rudimentary understanding of their ecology.

Overall, regulation of the water regime for human and agricultural use is not currently a widespread concern. However, the environmental and economic implications of constructing dams/barrages on the highly seasonal rivers and estuaries are not known.

2.1 Irrigation and agriculture

Major alteration to the water regime for human and agricultural use has greatly affected the Ord River in the Kimberley. The Ord is regulated by two dams, one at Lake Kununurra constructed in 1963 and the other at the larger Lake Argyle which was completed in 1972 and located 52 km upstream (Graham & Gueho 1995). It is planned to augment the 15 000 ha of land currently irrigated by a further 25 000 ha and eventually reach 70 000 ha in total. Nevertheless, the success of the Ord River Irrigation Area, after a long period of cropping and marketing trials, could encourage further damming of rivers. Sugar cane has recently been hailed as a successful crop and there are plans to recommence cotton growing (ASTEC 1993). There are also increasingly regular calls for the development of other irrigation schemes (eg on the Fitzroy River in Western Australia).

In the past, broad-scale agriculture in northern Australia has not been overly successful with the failed rice development at Humpty Doo in the Northern Territory being a well known example (Mollah 1982). The problems with agricultural development in northern Australia were critically and controversially identified two-three decades ago by Davidson (1972). Agriculture has been constrained by infertile, leached soils, a harsh climate, and an abundance of pest species. Cropping and horticulture are not major issues within wetlands in northern Australia. However, further development for agricultural use cannot be ruled out. This includes regulated grazing of buffalo and cattle, and the development of land for horticulture, rice and tree crops such as mangoes and cashews.

As a consequence of the construction of the dams on the Ord the river now runs all year round downstream of the dams and discharges into Cambridge Gulf. Thus, the Ord is now one of a small number of perennial rivers in northern Australia. There is little information on the effect of the river flow on the wetland conservation area of Parry Lagoons downstream of the dams (Graham & Gueho 1995). Further, the effect on the groundwater has not been ascertained. The importance of seasonal flows along these rivers for stimulating fish migrations and spawning and to flush vegetation and sediment from channels and waterholes is now well known (Griffin 1995, Lukacs 1995, Bishop et al 1995). Continuous flow or aseasonal releases of water can degrade the river channels through waterlogging of the banks and consequent slumping, loss of riparian vegetation, increased erosion and sedimentation, and encouraging the establishment of weed species (Bunn & Davies 1995, Lukacs 1995).

2.2 Grazing and ponded pasture

The water regime of wetlands is also under threat from steps to increase the potential for grazing of cattle and buffalo. Specifically, the construction of ponded pastures, usually with introduced grass species, has become a contentious issue in Queensland and is developing in the Northern Territory. Large scale artificial ponding on the floodplains has the potential to diminish the primary productivity of the estuaries by retaining water rather than allowing it to run-off at the end of the Wet season (Griffin 1995). In the Northern Territory, such ponding is primarily an issue on the Mary River and it is intertwined with attempts to combat premature drainage of freshwater and intrusion of saline water into formerly freshwater habitat following the breakdown of the natural levees (Griffin 1995). Ponded pastures have not been widely established on Northern Territory wetlands, but they have certainly attracted great interest and could become more favourably viewed by pastoralists. The grass species that have been introduced to such ponds in coastal Queensland have already been introduced to Northern Territory floodplains (Clarkson 1995, Fulton 1995, Jaensch et al 1995).

Humphries et al (1991) stated that perhaps the most insidious and uncontrolled threat to the native communities of northern Australia are introduced pasture grasses, which are implicated in causing changes to ecosystems by changing fire seasonality, intensity and area of burn. Introduced semi-aquatic grasses currently promoted for ponded pasture are infilling tropical wetlands and threatening waterfowl habitat.

The Northern Territory Department of Primary Industry and Fisheries (DPIF) is currently widely promoting the use of some very invasive introduced pasture species at field days and through extension literature, for example olive hymenachne (*Hymenachne amplexicaulis*), aleman grass (*Echinochloa polystachia*) and para grass (*Brachiaria mutica*). These species are included by Humphries et al (1991) in their list of the 18 'top' environmental weeds in Australia. With the DPIF actively promoting these species before research examining the effects of proposed introduction can be undertaken, this effectively means that by the time it is known, one way or the other, it may be too late. There is clearly a need to improve the consultative processes between stakeholders, in order to minimise future possible conflicts.

2.3 Mining

The water regime of wetlands can be altered by mining developments in two main ways – water diversion and storage, and changes in sedimentation patterns. These are both likely to be known quantities and can be controlled. Mining can affect wetlands; in most instances this can be confined to the river or to the catchment downstream (Lake 1995). Mining for minerals in northern Australia does not currently greatly affect the water regime of wetlands.

Mining for uranium occurs adjacent to wetlands and streams in Kakadu National Park, but not actually in the wetlands.

Sand extraction from streams is a different story. Extraction of sand from the Mary River has altered sedimentation patterns and offshore shoals in van Diemen Gulf (Sessional Committee on the Environment 1995). The large scale extraction and later discharge of groundwater, as is proposed for the Century mine in north-western Queensland, has introduced a new and controversial management issue. There is also potential for the development of new mines and even dredging operations in wetlands, such as those being discussed for diamond extraction from Cambridge Gulf in Western Australia. Thus, whilst mining is not currently causing great disruption to the water regimes of wetlands in northern Australia, there is considerable potential for this to change rapidly.

2.4 Climate change

Coastal wetlands are generally low in elevation and therefore vulnerable to climate change, including sea level rise. This is a pertinent issue in northern Australia where macro-tidal ranges (5–8 m) already occur and storm surges associated with violent cyclonic depressions are pronounced. The extent of vulnerability will depend on the physical characteristics of the individual wetland and coastal conditions. Environmental responses to climate change are manifested through hydrological, hydrodynamic, geomorphological and ecological processes (Bayliss et al 1998). Current scientific wisdom is that global warming will increase over the next few decades with a high degree of probability (Butterworth 1995). CSIRO (1994) have predicted that by 2030 climate in northern Australia will most probably change by: 1–2°C rise in temperature; up to 20% increase in summer rainfall; increase in rainfall intensity; more extreme events, such as floods, hot days and dry spells; 5–15% increase in potential evaporation; stronger monsoonal westerly winds; and 20 ± 10 cm rise in sea level. These changes are sufficient to greatly alter the ecological character (*sensu* Finlayson 1996) of the coastal wetlands and the values and benefits currently derived from them (Bayliss et al 1998).

The extent of ecological change as a consequence of climate change is not known, but Bayliss et al (1998) have drawn attention to the very real possibility that the highly valued freshwater floodplains may become saltflats, which has already occurred, as a consequence of saline intrusion, in the Mary River (Woodroffe & Mulrennan 1993). The lower Mary River is undergoing rapid change (Woodroffe & Mulrennan 1993, Fulton, 1995) and could provide an analogue of global warming induced change (Bayliss et al 1998). To date, an estimated 17 000 ha of freshwater grassland and *Melaleuca* woodland have been degraded by saline intrusion and a further 5500 ha are immediately threatened. Steps to reduce the extent of saline intrusion have been only partially successful. The ecological consequences of the saline intrusion are blatantly obvious (replacement of the highly diverse and productive grass/woodland habitats with salt flats), but the consequences of large scale engineering solutions are not known and are even questioned as being of practical use (Bayliss et al 1998).

Non-coastal wetlands are less likely to suffer such extreme change (usually meaning detrimental change) as a consequence of global warming. In fact, increased or more intense rainfall may benefit many organisms and even create new wetlands and wetland habitats. Increased temperature and more extreme rainfall events could lead to a call for converting wetlands into water storage lakes. Increased growth of aquatic and riparian vegetation could also lead to increased channel blockages and snags. The extent and effect of such changes are not known, although Lukacs (1995) reports that large stands of emergent plants can cause increased sedimentation and siltation of wetlands.

3 Water quality

Mining, horticulture, pastoralism, population centres, tourism and other land management practices can all potentially impact on water quality by increasing nutrient loads, sediment and turbidity levels, and lead to the introduction of toxic substances. Water pollution can occur as a result of direct discharges to streams or water bodies (eg sewage and effluent discharges) or from diffuse (run-off from agricultural lands) or indirect (eg groundwater salinisation) sources.

3.1 Mineral processing and extraction

Finlayson et al (1988) claimed that the major potential pollution threat to water quality in the Northern Territory was from mineral extraction and processing. It is probably more accurate to say that mining provides the major potential point source of pollution and hence is now generally closely regulated. In the past, the example of Rum Jungle Mine was often quoted due to its problems with overburden heaps and copper leachate piles slowly oxidising and producing acid drainage which polluted the East Finniss River. The water in the open-cut pits also became acidic and contained heavy metals, and the tailings dam was a low-level radioactive hazard. Recently, the Ranger uranium mine in the Alligator Rivers Region has been the subject of concern over possible pollution of downstream wetland areas, although water from a restricted release zone on the mine has not been released. Any proposed water release from this zone would be subject to a strict regulatory and monitoring regime (Johnston 1991).

3.2 Tourism and recreation

Diffuse pollution could come from a number of sources that differ greatly in scale and potential impact. Chemical pollution from sunscreens, soaps and insect repellents used by swimmers may become a problem in the small permanent waterholes of popular recreational areas, such as those in Kakadu and Litchfield National Parks. A preliminary investigation of the potential for such problems in Kakadu did not find any signs of pollution, although further tests were recommended (Rippon et al 1994). Fuel spillage from commercial boats and shipping in port areas could threaten mangrove habitats. Similarly, a variety of wetlands could be subject to at least small scale pollution from fuel spillages from boats used for tourism and recreational purposes.

3.3 Agricultural chemicals

The wetlands of northern Australia are generally not as subject to assault from pesticides as those in southern Australia. Expanded horticulture and irrigated cropping could alter this. The expansion of the Ord River irrigation system is of prime concern, especially given past experiences with the use of agricultural chemicals in this region. Only limited information on such chemicals in the waterways and wetlands is available. The secondary effects of such chemicals, for example, causing the decline of zooplankton species that prey upon phytoplankton that would otherwise result in noxious algal blooms, are also poorly understood (Lukacs 1995).

The use of herbicides for weed control on coastal wetlands in the Northern Territory has attracted a large amount of support (Schulz & Barrow 1995), but has not generally been accompanied by ecotoxicological assessments using local species. One exception is the investigation into the effects of spraying the floating weed *Salvinia molesta* in Kakadu National Park with a kerosene surfactant mix (Finlayson et al 1994b). Based on ecotoxicological and chemical testing and modelling of potential nutrient release from decaying plant material no adverse effects were detected. *Mimosa pigra* has received a great deal of attention and large scale herbicide control programs using five different herbicides have been conducted (Schulz & Barrow 1995). These chemicals are applied in desperate attempts to control the further spread of this noxious weed. Given the extent of the program, as witnessed by the following comments from Schulz and Barrow (1995) – '*the largest application of herbicide ever undertaken in the Northern Territory … and probably the single largest application of Graslan to a wetland environment in the world*' – a risk assessment incorporating ecotoxicological testing with local species could be a useful adjunct to the management processes.

3.4 Eutrophication

Nutrient enrichment of waterbodies by cattle and feral animals is of concern, particularly in the more arid areas. Grazing is a major land use in northern Australia and the presence of cattle within catchments presents considerable potential for deterioration of the water quality (Griffin 1995). Trampling and grazing of the vegetation that holds the sediment in place, and the deposition of dung are the major concerns. Subsequent water quality problems, such as eutrophication, reduction in clarity and algal blooms, can result. Flushing of large quantities of dung into rivers and pools early in the Wet season can add significantly to the nutrient pool and biochemical oxygen demand. Natural systems that are highly stratified (eg billabongs) at the end of the Dry season (Walker & Tyler 1984) may in fact become anoxic with the sudden influx of land-derived nutrients.

The disposal of sewage from urban areas is a well documented threat to coastal habitats in Australia. In northern Australia this is likely to occur around the major settlements and possibly also near sensitive recreational areas.

3.5 Salinisation

Salinity is a major concern in the coastal floodplains of the Northern Territory. Saltwater intrusion from the breakdown of natural levees that separate the freshwater floodplains from the tidal rivers and mangroves is a major threat (Woodroffe & Mulrennan 1993, Jonauskas 1996). It is suspected that feral animals may have contributed to these events, but it is equally argued that they are caused by natural processes that are being exacerbated by human activities, including climate change (Woodroffe & Mulrennan 1993, Bayliss et al 1998). Whatever the cause of the problem, it is evident that the floodplains are under threat and that this threat is extending and engulfing grazing land and valuable wildlife habitat (see papers in Jonauskas 1996). Adjacent floodplains have also been subject to saltwater intrusion, but not to the same extent as the approx 17 000 ha alongside the Mary River. Salinisation of the Mary River floodplains probably represents the most widespread water quality problem in northern Australia.

3.6 Burning practices

Fire is a conspicuous element of the northern landscape. The regularity of fire in the Wet-Dry tropics has affected wetlands, but quantifiable information is, on the whole, absent (Douglas et al 1995). Fire remains a contentious issue in the northern landscape (Andersen 1996).

Broadscale fire regimes can affect the water quality of wetlands. Direct effects can result from burning of the dry floodplains and either the loss of nutrients and organic material, or the deposition of excessive amounts of material in waterholes (Braithwaite & Roberts 1995).

Catchment burning can also effect wetlands by adding ash and suspended solids. Destruction of the riparian zone by fire (and other means) can increase light availability and alter the energy input via leaf litter. The effect of burning practices on aquatic/wetland systems is still poorly known despite the major role fire has in management regimes for the savanna landscape of northern Australia (Douglas et al 1995). Lake (1995) points out that unlike possible pollution from point sources, such as mining developments, other major land use disturbances, such as those resulting from fire and grazing practices, are not strictly regulated.

4 Biodiversity and conservation

The conservation status of wetlands of northern Australia has not been assessed and indicators of ecological integrity have not been developed. It is well recognised, however, that many of the wetlands are valuable for conserving biological diversity, but are under at least 'low-level' threat by increased land use activities and invasive species (Finlayson et al 1988, 1991, Finlayson & von Oertzen 1993). Compared with elsewhere in Australia the wetlands of northern Australia are largely intact. Relatively few have been lost, although mangroves around Darwin are now potentially threatened by infilling and clearing for port and urban developments. The extent of degradation is unknown, although Finlayson et al (1988) and Finlayson and von Oertzen (1993) point out that cattle grazing has degraded the natural vegetation of many wetlands.

4.1 Mangrove degradation

Current threats to mangrove communities are restricted to localised areas in the vicinity of Darwin. Threats arise from nutrient enrichment, construction of causeway embankments, removal and reclamation for new subdivisions, stormwater run-off and changes to the hydrology and salinity gradients from mosquito eradication drains (Dames & Moore 1984). Further pressure is likely to come from proposed recreational, residential and industrial developments around the harbour.

Recognising the need to conserve mangrove and coastal environments, the Northern Territory government has developed a management policy aimed at 'achieving a coordinated and effective approach to coastal management issues' (Singer & Wright 1985). A mangrove resource data base was established (Dames & Moore 1984) to compile available information on the mangroves of the Northern Territory and associated coastal environments. The data base contained an adequate description of mangrove distribution, but little information on associated flora and fauna and mangrove dependent marine organisms. Much more information on these subjects has become available in recent years (McGuinness 1992, Brocklehurst & Edmeades 1995, Noske 1996, Youssef 1997).

Singer and Wright (1985) considered that by international standards the threats from development to Northern Territory mangrove communities were negligible. However, development has proceeded since that assessment was made and without additional carefully collected scientific data it will be difficult to rationally resolve the conflicts that could arise between conservationists and coastal developers.

4.2 Pest species

The ecological character of many wetlands in Australia has been adversely affected by invasive plants and animals, many of them alien species. Fourteen of the top eighteen environmental weeds in Australia invade wetlands (Humphries et al 1991). Humphries et al

(1991) make the points that tropical wetlands and riparian zones are at great risk from weed invasion.

> riparian systems are most heavily invaded within any given environment and are therefore at greatest risk. The importance of these systems, particularly at times of drought, increases the ecological seriousness of this situation.
>
> Tropical wetlands are in critical danger.

The reasons for weed invasion are manifold, but it is believed that, in the Northern Territory, it is the high levels of disturbance caused by domestic and feral animals to riparian fringes, floodplains and ephemeral flats, that make these areas highly susceptible to weed invasion (Cowie & Werner 1993, Griffin et al 1989, Reid & Fleming 1992). Feral grazing animals have invaded many northern Australian wetlands. Other significant threats come from cane toads (*Bufo marinus*) and exotic fish, particularly the mosquito fish (*Gambusia holbrooki*).

For many of the main pest species the extent of their invasion of wetlands and streams has been described to some extent. In many instances the biology of the species may also be known or is being studied (eg *Mimosa pigra*, *Salvinia molesta*). Surprisingly, however, vital information on the ecological changes wrought by these species is often confined to a few isolated studies, if any, and/or anecdotal evidence. For example, a great deal of effort has been directed towards developing both chemical and biological control of *Mimosa* and *Salvinia*, but relatively little effort has been directed towards assessing the extent of ecological change caused by these species.

Economic analyses of the losses caused by pest species are also not common. These can be done on the basis of lost agricultural production and in some cases (eg grazing land covered by weed species) losses in productive capacity may be very obvious, but economic evaluation of 'natural' wetland ecosystem functions is only in its infancy (eg Turner & Jones 1991). Unless we can 'price' the ecological consequences along with the economic consequences of such massive weed invasion we may never really know the extent of our 'loss'.

In the following text a general description of major pest species is given. A complete list of potential or minor pest species is not given.

4.2.1 Acacia nilotica (prickly acacia)

Prickly acacia is native to Africa and West Asia where it is found in acacia-savanna along drainage lines, bores and dams. It currently covers about 7 M ha in arid to subtropical regions of Queensland (Smith 1995). In the Northern Territory, small infestations occur along the Barkly Highway with an outbreak reported on Cattle Creek Station in the Ord-Victoria Plains biogeographical region. Currently, all infestations are under control.

4.2.2 *Brachiaria mutica* (para grass), *Echinochloa polystachya* (aleman grass) and *Hymenachne ampexicaulis* (olive hymenachne)

Para grass, aleman grass and olive hymenachne are grass species that are commonly referred to as ponded pasture species (Clarkson 1995). Para grass is a highly invasive alien species that has spread across many wetlands in northern Australia. In places it has been aided by deliberate plantings as a pasture species and in others it has spread from pastoral areas into nature conservation zones (Lindner 1995, Miller & Wilson 1995, Clarkson 1995). Deliberate planting of para grass now occurs in both Queensland to develop ponded pastures (Clarkson 1995) and in the Northern Territory for stabilising floodplain surfaces following control of mimosa (Miller & Wilson 1995, Cook & Setterfield 1995). Aleman grass and olive hymenachne have been introduced more recently for use in ponded pastures in Queensland (Clarkson 1995) and at a few locations in the Northern Territory.

While there are no rigorous scientific data about the impact of these species, there is a lot of anecdotal evidence that they form a monoculture and are, in certain situations, invasive. This means, at the very least, reduced biological diversity in the affected areas, and therefore structural and functional deterioration of the ecosystem. At worst, it could mean the complete alteration/modification of entire ecosystems. These pasture species are a particularly difficult and even intractable problem given that pastoralists are clamouring for them and conservation authorities are concerned over their potential to completely alter the ecological character of wetlands. Fisheries authorities are also concerned that ponded pastures will prevent freshwater run-off to the estuaries and reduce the primary productivity of these habitats and also prevent migration by juvenile barramundi (Clarkson 1995, Griffin 1995). There seems to have been little attempt to supplant the introduced grasses with native species; presumably due to the ease of establishing the introduced species and their greater value as stock food.

4.2.3 *Eichhornia crassipes* (water hyacinth)

This floating introduced species has long been a major weed in Australia (see Mitchell 1978, Finlayson & Mitchell 1982, Forno & Wright 1981, Wright & Purcell 1995). Biological and chemical control methods have been implemented and it is not now generally regarded as a serious threat to wetlands, although local problems still occur or could occur (Fulton 1995). It is not known if this change has occurred as a consequence of control measures or whether the plant has established a balance after an initial period of explosive growth. It occupies similar habitats as *Salvinia molesta* and presumably has a similar, but largely unknown effect on wetlands.

It is more widespread in coastal wetlands in Queensland (Finlayson & Gillies 1982) than inland. A number of incursions have occurred in the Northern Territory, but is only known to have established at one site, Fogg Dam near Darwin.

4.2.4 *Mimosa pigra* (mimosa)

Mimosa is an aggressive prickly shrub, native to Central America, that can form dense monospecific stands on the floodplains of the Northern Territory. At present, it is confined to the coastal floodplains of the Northern Territory, in an arc extending from the Moyle River in the west to the Arafura Swamps in Arnhem Land (Lonsdale et al 1995). It covers an estimated 80 000 ha and is a prolific producer of seeds that are readily dispersed by water, vehicles and animal vectors. There is strong circumstantial evidence to link vehicle movements with new occurrences (Cook et al 1996). Natural expansion of established stands is very fast.

Research efforts have centred on finding suitable biological control agents with a number having been released. Integrated control programs are also in place and incorporate biological control along with the use of herbicides, mechanical removal (chaining), burning and revegetation (Miller & Wilson 1995, Schulz & Barrow 1995). In Kakadu National Park a continuous ‘search and destroy’ policy has successfully been in place for the last decade (Cook et al 1996). Outside the park, however, the story is more one of gloom and expensive chemical control programs that are partly government-funded and undertaken on pastoral leases and Aboriginal lands (Schulz & Barrow 1995). Management emphasis on control techniques, particularly biological means, continues and importantly, is now complemented by post-control rehabilitation of the formerly infested areas.

4.2.5 *Parkinsonia aculeata* (parkinsonia)

Parkinsonia is a branched spreading tree from South America. It can grow to 6 m in height and in a variety of soil types and is often found around bores, dams and along creeks and riverbanks (Smith 1995). It is widespread on pastoral leases on the Barky Tablelands and in the Victoria River District. Control is undertaken by using biological control agents along waterways and herbicides away from the major waterways. Further, it can dominate the vegetation near watercourses and ephemeral lakes in the Northern Territory, such as the Playford River which terminates in Lake DeBurgh and Corella Creek terminating at Corella Lake (D Gracie pers comm). Chemical control has been carried out, but discontinued in some areas of the Northern Territory because of the extent of the seed reserves present upstream (D Gracie pers comm).

4.2.6 *Pistia stratiotes* (water lettuce)

Water lettuce is a floating aquatic plant that was first recorded in the Northern Territory from lagoons near Darwin about 50 years ago. It has since been recorded from a number of locations but does not appear to have caused the serious problems reported elsewhere in Australia (Mitchell 1978) and there is some question as to whether or not the species is alien or native to the Wet-Dry tropics (Gillett et al 1988). It is important to note though, that under suitable conditions, for example in streams and channels in the lower Burdekin in Queensland (Finlayson & Mitchell 1981) it can become a weed.

4.2.7 *Prosopsis limensis* (mesquite)

A small tree to 6m, mesquite is found on heavier clay and loam soils. It is a native of North and South America and is established as a weed in Queensland and the Northern Territory (Smith 1995). It is found mainly in the Barkly Tablelands with isolated occurrences near Katherine and further south in the arid zone. Mesquite appears to be on the increase on the cracking clay soils of the Barkly Tablelands. Herbicides have been largely ineffective. It is spread readily by stock by ingestion and later defecation, with isolated plants appearing in previously weed free locations (D Gracie pers comm). A related species *Prosopsis glandulosa* (honey mesquite) has been found on Nicholson Station in Western Australia abutting the Northern Territory border.

4.2.8 *Salvinia molesta* (salvinia)

This free-floating aquatic fern, originally from South America, has been the centre of much attention in Australia and elsewhere (see Mitchell 1978, Finlayson & Mitchell 1982, Harley & Mitchell 1981, Room & Julien 1995, Storrs & Julien 1996). In the Northern Territory infestations have been found at Nhulunbuy, and on the Finniss, Howard, Daly, South Alligator and East Alligator Rivers; the last two in Kakadu National Park (Miller & Wilson 1989, Finlayson et al 1994a, Julien & Storrs 1993). It is not widespread in the northern region of Queensland, but major outbreaks have been recorded in regions outside of the Wet-Dry tropics, such as near Mt Isa (Finlayson et al 1984 a, b) and along the east coast (Finlayson & Gillies 1982, Harley & Mitchell 1981, Finlayson & Mitchell 1982).

Several infestation have been successfully eradicated by the DPIF using herbicides, including a major infestation on the Adelaide River in the Northern Territory (Miller & Pickering 1988). Generally, management is reliant on biological control using an introduced weevil that has had variable levels of success (Room et al 1981). Storrs and Julien (1996) have recommended the adoption of integrated control measures with chemical spraying being strategically allied with attempts to spread the weevil to all known infestations. The use of herbicides in some locations raises many concerns; some of these were addressed by Finlayson et al (1994a).

Despite being a widespread weed in eastern Australia for more than three decades very little is known about its ecological effect on wetlands. Salvinia competes directly with other plants for light, nutrients and space. The weed invariably becomes dominant over submerged floating plants and smaller floating plants, such as *Azolla* and *Lemna* spp, by cutting off their light supply. The water under a salvinia mat has lower oxygen and higher hydrogen sulphide concentrations, lower pH, and higher temperature than open water nearby (Mitchell 1978). It also dramatically alters the nutrient status of billabongs (Storrs & Julien 1996), reducing nutrient availability to other biota, through growth or storage within the plant (Finlayson et al 1984a, Room 1986).

4.2.9 *Bubalus bubalis* (Asian water buffalo)

The feral Asian water buffalo once proliferated on the coastal floodplains of the Northern Territory and were considered responsible for widescale destruction of the native vegetation by direct grazing, trampling and wallowing and indirectly by destroying levee banks and contributing to premature drainage of freshwaters (see Finlayson et al 1988). However, throughout the 1980s the feral herds to the west of Arnhem Land were almost eradicated as part of a national program to prevent diseases being transferred to domestic stock. Buffalo still exist in large numbers in Arnhem Land as this area was not involved in the eradication program.

The problem, perhaps ironically, is now not so much one of too many buffalo, but one of too few buffalo! The rapid removal of a major grazer from the floodplains and billabongs has resulted in large scale ecological change (Finlayson et al 1991, 1993). Both native and alien plant species have spread to cover the areas formerly laid bare by the buffalo; billabongs have become choked with red lilies and sedges, and grasses, including para grass have overgrown stream and billabong banks and spread across the floodplains. In this instance the ecological consequences of removing the buffalo and thereby overcoming one series of problems, did not seem to receive sufficient attention.

It is important to note, however, that the impetus for removing buffalo came from funding provided for disease control in feral stock; environmental concerns were not to the forefront (Skeat et al 1996). Given that funding was not given for large scale environmental management it is expected that buffalo numbers will naturally increase again in areas such as Kakadu after the disease eradication program funding ceases in 1997.

4.2.10 *Sus scrofa* (pig)

The feral pig is widespread over the Australian environment. It has caused widespread damage rooting with its snout and trampling around the edges of wetlands and adjacent forests. This disturbance provides great potential for the rapid establishment of weed species. The implications for the lack of control of pigs on weed management are very serious. In the Northern Territory there is evidence that pigs have proliferated following the removal of the feral buffaloes from the floodplains (Corbett 1995). This seems reasonable given that many buffalo formerly trampled and destroyed many vegetative morsels that would have been favoured by the omnivorous pigs. However, the influence of climatic factors, for example, on pig numbers can not be discounted as a contributory factor.

Control of pigs is widely regarded as difficult depending on the terrain. Control programs utilise trapping, hunting with dogs, poisoning and helicopter shooting. A further factor to consider when assessing the effect of pigs on the environment and the need for widespread control measures is the increasing acceptance of pigs by some Aboriginal people as a major part of their diet. Thus, they may want to retain sufficient numbers of pigs for hunting purposes.

4.2.11 *Bufo marinus* (cane toad)

The cane toads have been present along the eastern coast of Queensland since the 1930s and over the last decade have moved westwards into the Northern Territory to the vicinity of the Roper River. The rate of natural spread of the cane toad is approximately 30 km per year (Freeland & Martin 1985). The available data do not support the notion of the cane toad having a long-term catastrophic impact on native fauna. No species in Queensland has become threatened or gone extinct as a result of the cane toad's introduction 50 years ago (W Freeland pers comm). Recent studies on the toad indicate that whilst all stages of the life cycle are potentially toxic and are avoided by many predators, they are successfully consumed by others (Alford et al 1995). Some native frog larvae and snails are negatively affected and toad larvae can compete strongly with larval native frogs. There is strong anecdotal evidence that predators such as goannas initially decline after the arrival of cane toads, but after a short period re-establish and/or learn more effective techniques of consuming the toads and avoiding the toxins that they carry (W Freeland pers comm).

The reaction of local Aboriginals to the impact of toads on their traditional food sources is not known (P Whitehead pers comm). Noting that Aboriginal people are increasingly accepting feral animals as part of their 'traditional' lifestyle it could be pertinent to incorporate an Aboriginal perspective on this species before further effort is expended.

4.2.12 Exotic Fish

No major exotic fish incursions have yet happened in northern Australia. This contrasts markedly to the dominance of introduced species, especially trout, carp and mosquito fish, elsewhere in Australia (Arthington 1986, Fletcher 1986). Localised incursions of several freshwater aquarium species have occurred in the Northern Territory. Guppies (*Poecilia reticulata)* are established in Nhulunbuy Town Lagoon; platys, mollies and swordtails (*Xiphophorous maculatus*, *Poecilia latipinna, Xiphophorous helleri)* in Gunn Point Creek (believed to be escapees from the Prison Farm!).

Mosquito fish (*Gambusia holbrooki*) have been actively introduced into much of southern and eastern Australia as a means of controlling mosquitoes. They occur in northern Australia at localised sites. They are voracious feeders and seemingly have a major influence on the structure of invertebrate communities without being very successful in controlling mosquitoes. For any eradication strategy to be accepted the ecological degradation caused by these fish needs to be demonstrated; this information is either inconclusive or is lacking (Fletcher 1986).

4.3 Riparian degradation and grazing

Soil erosion due largely to land management practices has been a feature of the riparian areas of many large river systems of northern Australia (eg Ord and Victoria) causing siltation and filling of waterholes, collapse of bank structure and loss of riparian vegetation (Winter 1990). Land degradation and habitat alteration caused by the introduction of exotic herbivores appear to be the principal factors causing change in status of birds in arid Australia. Introduced predators are implicated in some cases and altered fire regimes may play a part (Reid & Fleming 1992).

Overgrazing by cattle and feral animals can lead to pronounced seasonal and other changes in run-off patterns and to increased sediment loads. Vegetation changes, chiefly involving the replacement of deep-rooted trees by shallow-rooted grasses, can also lead to marked changes in hydrological patterns as well as changes in water quality, of which increased salinity can be among the most important.

The spatial extent and intensity of the domestic stock threat varies from region to region dependent on the distribution of commercial livestock grazing and individual property management approaches (J Reid pers comm). Riparian zones (fringing vegetation), particularly around permanent waterholes which are the foci for water-dependent (drinking) grazing animals, have probably been most degraded in terms of vegetation compositional and cover changes. Increasing damage occurs as conditions become drier (drought) and as animals become more focused on remaining watering points (J Reid pers comm).

5 Social and sectoral issues

The utilisation of wetlands and wetland products raises a number of specific and general concerns for conservation and land/water management agencies. Access to and maintenance of the ecological character of the wetland habitats have received a great deal of attention and been subject to land use planning and zoning. However, often this has been done on a sectoral basis with little regard for other sectors or groups within society. The advent of widespread tourism and recreational activities has seen conflicts develop over access for recreational fishing (Julius 1996). Further, quarantine measures for weed control have been controversial, such as those on the Magela in Kakadu for salvinia and for noogoora burr on the Ord River.

In many instances the management agencies and policies required for effective wetland management, especially multiple use, have been inadequate. Attempts to break down such sectoral divides have seen the Northern Territory Government conduct extensive consultation and form committees to address the complex problems on the Mary River wetlands. Further, there are ongoing concerns about management of and access to Aboriginal-owned wetlands.

In the following discussion major social uses of wetlands are addressed in terms of their effect on biological diversity and conservation. Thus, some of the issues that are addressed under headings above are reintroduced but with a different emphasis. It is perhaps instructive to note at this stage that sectoral divides and associated underlying socio-economic and political issues that affect land use decisions are being seen more and more as the prime reasons for ineffective wetland management (Hollis 1992, Finlayson 1994, Hollis & Finlayson 1996).

5.1 Tourism and recreational activities

Recreation activities in wetland areas include picnicking, camping, boating, hunting, bird watching, bushwalking and amateur angling. Tourism and recreational activities are strongly influenced by factors such as the presence of water and accessibility. Access to many wetlands is limited for much of the year to specialised vehicles. As a result, wetland recreational use is generally restricted to floodplain edges, billabongs and major channels or creeks. Vehicular access has caused erosion along levee banks resulting in denudation of billabong and river frontages. Similarly, poorly chosen or constructed boat launching facilities can cause erosion. These problems can be overcome by excluding vehicles from the forward slopes and adopting some care when choosing and constructing boat ramps. More difficult problems to overcome include the dispersal of seeds of noxious weeds, disruption of breeding colonies of waterbirds (Jaensch et al 1995) and pollution of waterholes (Rippon et al 1994, Lindner 1995) by vehicles and boats.

Hunting is a particularly controversial recreational issue with great concern being expressed over the ethics of such activities. Hunting disturbs breeding birds (Jaensch et al 1995) and can result in lead poisoning of birds from spent shotgun pellets (Whitehead & Tschirner 1991). Hunting of geese by non-Aborigines has recently undergone increased regulation and has been subjected to intensive research and monitoring, especially in the Northern Territory.

Aerial surveys are used to acquire data for determining the timing and duration of the hunting season and bag limits. Current hunting pressure does not appear to be heavy in relation to the size of the waterfowl populations. In view of an expected increase in hunting activities the recent steps of initiating research and maintaining contact with the hunting fraternity are timely. Hunting by Aboriginal people also occurs, but this is generally unregulated and at times controversial (see Ponte et al 1994).

Probably the most important recreational activity in northern Australian wetlands is fishing, especially for barramundi (*Lates calcarifer*). The environmental impacts of large numbers of anglers extend beyond placing pressure on fish stocks; however, there is very little information on the extent of this pressure. Barramundi stocks in the Northern Territory were over-exploited during the late 1970s and early 1980s leading to extensive regulation of both commercial and recreational fishing (Grey & Griffin 1979, Griffin 1995). Recreational fishing is particularly important on the Mary River and in Kakadu National Park in the Northern Territory (Griffin 1995). Given the popularity of recreational fishing there is an increasing problem of 'overcrowding' at highly favoured or easily accessed sites.

The current low level of recreational impact on northern Australian wetlands is probably attributable to low population pressures. With increased population growth it is likely that the pressure will increase. Without sound management practices environmental degradation could cause a reduction in the current aesthetic and recreational value of these areas.

5.2 Pastoralism

Pastoralism has been the most extensive land use in northern Australia since European settlement and is currently the major land use outside of nature reserves (Whitehead et al 1992). The wetland areas are the most nutrient rich and mesic areas and thereby produce the best forage for livestock. There is much debate on the efficacy of pastoral activities in northern Australia with a popular conception being that conservation objectives can only be met by the complete removal of grazing. Pastoralists counter that they are modifying their management practices (Curry & Hacker 1990, Cadzow 1993) and point to Landcare initiatives as evidence. However, there are differing views of the usefulness of Landcare in the rangelands context and critics claim that Landcare has been appropriated in some instances by entrenched interests thereby excluding innovation (Reid 1994).

Widespread modification of floodplains to achieve pastoral objectives will probably reduce the range of wetland habitats (Whitehead et al 1992). There is increasing pressure on wetlands as alternative sites for grazing during the Dry season. Further, exotic pasture species such as para grass (*Brachiaria mutica*) are being introduced into areas formerly occupied by native grasses (Liddle & Sterling 1992) to increase productivity. It is feared that homogeneous and 'regulated' floodplains will not show the idiosyncratic response to variable rainfall that maintains the current habitat diversity (Whitehead et al 1992). The actual role of grazing in maintaining habitat diversity is not clear and under some circumstances it could be used to promote vegetation diversity. However, the introduction of exotic grass species that displace native species (Cowie & Werner 1993), especially if coupled with ponded pastures (see above) is not generally supported by conservation and fisheries interests (Whitehead et al 1992; Griffin 1995, Jaensch 1995) and is, at times, a highly emotive issue (Julius 1996).

5.3 Aboriginal land usage

Under the Northern Territory Land Rights legislation Aboriginal people have regained large areas of traditional land – most often in drier areas, wetlands and other places not wanted by non-Aboriginal people. Nearly half of the Northern Territory is either Aboriginal land or under claim and over 85% of the coastline is now owned by Aboriginal people. Economic activity on Aboriginal land contributes significantly to the northern Australian economy. All the major mines and on-shore oil and gas wells in the Northern Territory are on Aboriginal land as well as some large scale cattle projects. The main tourist destinations including Kakadu and Nitmiluk (Katherine) National Parks are on Aboriginal land and Mabo-style land claims have been placed on other parks and vacant crown land.

Effective management of wetlands on Aboriginal land may require implementation of more appropriate locally driven agreements, covenants and protocols that reflect specific cultural heritage values. For this to be achieved consultation mechanisms may need to be reassessed and the political problems of land rights resolved (Graham & Gueho 1995). Assistance with best-practice environmental planning should be linked to full acceptance of the values and knowledge of Aboriginal peoples (Christopherson 1995). The issue of local community empowerment in conservation and land management is still vexed, but given the conservation value of wetlands on Aboriginal land across northern Australia it should not be ignored.

5.4 Burning practices

As already mentioned, fire is an integral and controversial aspect of land use and management in northern Australia. However, there is little actual research on the effect of burning patterns on wetland organisms and habitats. Douglas et al (1995) have reported on experimental work in streams. Traditional Aboriginal knowledge on fire behaviour still exists and Roberts (1996) reports that it has been used as the basis for directed and highly controlled resource management. Thus, it has been used to clear land for hunting purposes or to replace unwanted grasses, to break up the country into mosaic patterns and avoid destructive peat fires on the floodplains. Much of this knowledge has not been documented (Roberts 1996).

Land uses greatly affect the fire regime on wetlands and in conservation reserves there are attempts to prevent late Dry season burns (Press 1988, Graham & Gueho 1995). However, unregulated human activity can make this a difficult task with inappropriate fires being common. Grazing may impart some form of control over fire on floodplains by reducing the fuel load, although this is being affected by the introduction of exotic grass species and the removal of buffalo. Overall, the effect of fire on wetlands is little understood despite being a regular feature.

6 Restoration and creation

Given the large extent of wetlands in northern Australia and the comparatively low level of degradation and loss, compared with southern Australia, very little attention has been directed towards restoration and creation. The examples of Rum Jungle and the Mary River are two major exceptions (and are described above). The Rum Jungle restoration process was one dominated by removing or reducing the source of contamination from the abandoned mine site. The Mary River situation is far more complex with competing land uses and a seemingly intractable process being driven by geomorphic forces.

Small lakes such as that in Jabiru in the Northern Territory have been constructed but these are not common. The lake created at Fogg Dam in preparation for the rice growing ventures of the 1960s is now a valued conservation reserve and has been greatly modified to attract specific types of waterbirds. Such schemes have great public appeal and education value.

Far more attention is being directed towards the use of wetlands for treating wastewater, particularly that from mine sites (Noller 1995, Noller et al 1994, Nisbet 1995). This technology has been developed and trialed in southern Australia for urban and agricultural wastes (see, for example, Finlayson et al 1986, Finlayson & Mitchell 1983); however, it has only recently been adopted in northern Australia for mining wastes. Wetland plants are known accumulators of heavy metals (Finlayson et al 1984b, Outridge & Noller 1991) and can filter and retain suspended sediments (Finlayson & Chick 1983). Noller (1995) identifies three classes of wetlands as suitable for potential amelioration of mine wastewaters: existing wetlands; enhanced existing wetlands; and artificial wetlands. Both natural and artificial wetlands are being tested at the Ranger uranium mine in the Northern Territory for potential use during the operational phase of the mine and for long term passive treatment after rehabilitation of the mine site (Nisbet 1995).

Baird et al (1995) point out that whilst the capacity of wetlands to act as sinks for waste products may provide a powerful argument for their conservation it is also a dangerous one, since they effectively become surrogate landfill sites. Further, they argue that:

> While it is true that wetlands obviously have a tremendous capacity to accumulate and store chemical wastes, including contaminants, the concept of assimilative capacity of such systems is rarely addressed, except perhaps in terms of their capacity to store nutrients and some trace metals...

Overall, despite a lot of attention, there is a lack of information regarding the sustainability of wetlands when they receive significant inputs of contaminants. Thus, there is obvious concern over the use of natural wetlands for these purposes. The use of artificial wetlands may bypass such concerns, but not if they are also used as an excuse to degrade nearby natural wetlands. Similarly, enhancing degraded natural wetlands for wastewater treatment could be a double edged sword. Baird et al (1995) query whether wetland filters have a place in serious conservation strategies for wetlands.

7 Management priorities

The geographical area covered in this review is both large and sparsely populated. Nevertheless, many wetlands have been disturbed, or are threatened with disturbance. These disturbances could cause a reduction in, or total elimination of, one or more of the major biotic components, or a reduction in the diversity of wetland types. Whatever the type of disturbance, management for sustainable development (ie including conservation) should be designed to minimise unacceptable impact on the basic ecological character of the wetland. Determining what is an unacceptable impact is obviously a difficult task and must involve the myriad of societal considerations that are associated with land use planning. This task will be reliant on an adequate inventory of wetland values and benefits backed by rigorous risk assessments, monitoring and, where necessary, restoration of degraded habitats.

With the need for a valid and comprehensive information base in mind the following recommendations for regional priorities are presented.

7.1 Reserve system

Extension of a representative system of nature reserves and parks is one way of initiating processes that are required to enable wetland species and habitats to be conserved. By itself, however, the proclamation of reserves may not achieve a great deal. It is also necessary to develop and implement management practices that recognise the linkage between adjacent land uses and conservation management, especially where more than one jurisdiction is involved. It is essential that the reserve system is based on a sound inventory and is representative of local conservation needs and takes into account the historical land uses and future expectations of the local community. This may sound extremely complex, but it does provide the basis for local involvement in conservation associated with multiple land use planning at both a site and catchment level. In some instances, new or revised legislation and policies may be needed to underpin multiple and sustainable land use practices that provide the basis for successful conservation. Planning to incorporate tourism and recreational activities and access by traditional Aboriginal occupants and/or owners may also be needed at this stage. The use and regulation of fire for specific purposes may require specific attention.

7.2 Weeds

Weeds, particularly *Mimosa pigra*, pose a major threat to wetlands of northern Australia. The potential of weeds such as *Mimosa pigra* and *Salvinia molesta* to cause problems is well established and it is generally accepted that they should be controlled, if not eradicated. The status of other species is not always so clear and should be assessed on both a local and a regional basis. Such assessments should be done on a thorough analysis of known risks and hazards and include an analysis of the secondary consequences of the preferred control techniques. Unless the problem of weed invasion is addressed on the basis of sound and even proactive risk assessments the basic character and value of the wetland habitats could be degraded or even lost. Control techniques must be monitored as must the target areas after the control has been effected and, if necessary, further rehabilitation steps taken to stop reinfestation by the same or even other weed species.

7.3 Feral animals

Feral animals are present in many wetlands and, in some instances, have caused considerable disturbance to the natural system. The most prominent example, the Asian water buffalo on the coastal floodplains of the Northern Territory, has been subject to large scale control as a consequence of concerns over the spread of diseases to domestic stock. Once this program ceases the possible reintroduction of buffalo, whether through natural population growth or deliberate actions, should be handled with care. As with any management strategy, the success and effects of both the control program and any reintroduction need to be monitored and, if required, adjustments made. The impact and control of other feral animals needs to be assessed to provide the basis for conservation strategies to be implemented to prevent or reduce further undesirable change.

7.4 Agriculture

Agricultural development often results in diffuse sources of pollution and can have a significant effect on wetlands. Whilst it is difficult to control diffuse source pollution, attempts should be made to limit the extent of run-off of nutrients and pesticides from agricultural land to wetlands. To be fully effective this should involve management of the entire catchment and even the application of rigid controls such as those used to regulate mining enterprises. If the nature of the problem is assessed prior to development and adequate controls devised, the need for future remedial actions could be avoided. Point sources of pollution can be readily identified and are often, at least locally, extremely detrimental to the integrity of wetlands. Grazing is a particularly complex problem in some wetlands, especially if linked with the introduction of exotic pasture species and ponded pastures. Further attention, perhaps preceded by a moratorium on further introductions and ponding of floodplains, to the consequences of these actions is needed.

7.5 Tourism and recreational activities

The continued expansion of recreational activities into wetlands is likely to be a major problem for conservation authorities. The main areas of concern seem to revolve around the development of infrastructure and the extent of fishing activities. Tourism is a rapidly expanding industry and often linked with water and wetlands. Management plans that consider the potential impact of and even competition between recreational activities as diverse as fishing and hunting and bird watching are required.

7.6 Climate change

The problem of global climate change is probably one of the most perplexing for wetland managers. In the Northern Territory there is a suggestion that the salinisation of large areas of coastal floodplains may be due to natural processes. Thus, attempts to rectify the loss of freshwater habitat and prevent further extension of this loss may be attempting to combat natural processes. Monitoring of coastal processes and the rates of change are required as a base for planning further management steps even as current intervention steps are implemented. Management planning for such large problems will inevitably reflect community values and technological feasibility, but should not go ahead in ignorance of natural variability and environmental change. The problem of saline intrusion is seen as one of the most challenging for land owners and environmental planners alike, especially if linked to global scale climate induced changes.

7.7 Clearing and waste disposal

Clearing of wetlands for urban and industrial facilities is not widespread, but does have local impact. The retention of natural wetland functions should be at the fore of plans to develop such wetland habitats. On the same token the potential of artificial wetlands constructed to treat wastewaters should not be used as an excuse to degrade existing wetlands; it is not possible to fully replace the functions and values of natural wetlands with artificial wetlands. Further, the disposal of wastewater via natural wetlands should be discouraged unless it can be shown that the wetlands are not significantly altered. In this instance, further research into basic wetland processes and functions is needed.

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Mine water and waste management

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Abstract

Mines are important in wetland management because they usually degrade the water that they use, and because of their often remote location may be the major source of contaminant input to wetlands nearby. Mines use water for a number of purposes, with the degree of quality impairment dependent on the use and the extent to which the mine is required to ameliorate the degradation. Mines acquire water from a number of sources, and withdrawal of supplies from wetlands, if this occurs, may be as detrimental to the wetland environmental values as the addition of contaminants. Mines tend to categorise and store water according to the concentration and nature of contaminants contained in it. This is because the management of degraded water depends on its quality, and whether waste water can be released to the environment, either before or after treatment. These aspects of water use and management within mines are illustrated with reference to the Ranger uranium mine in the Northern Territory.

1 Introduction

Mines are significant users of water, and except in the case of elaborate water treatment, degrade the quality of the water, as determined by the presence of elevated concentrations of 'chemical indicators'. The exact nature of the chemical species added to water by the mining and milling process depends on the nature of the mine, and the degree of beneficiation of the ore on site. However, most mines will contribute to substantial increases in the turbidity and salinity of much of the water that they use, and most probably the mineral that the mine exists to exploit. Often mining activities will result in the release of significant quantities of acid (ie reduction in pH), and this will especially be the case where the ore or waste rock contains sulphide mineralisation that will oxidise to sulphuric acid on exposure to air.

It is self evident that increased burdens of mining-related materials in surface and groundwater can place additional stresses on wetland ecosystems, and the management of wetlands downstream from the mine depends critically on suitable monitoring and control of mining-related pollution sources. Because mines are frequently located in remote areas, they (and the urban infrastructure built to service them) may constitute the overwhelming source of anthropogenic physico-chemical inputs to wetlands in otherwise relatively undisturbed regions.

2 Uses of water in mines

2.1 Dust suppression

Blasting and excavating activities, and the deployment of heavy equipment, particularly trucks, over ore stockpiles and waste-rock dumps raises nuisance dust. In the case of uranium mines the dust must be suppressed to prevent exposure of workers to unacceptable levels of radiation. In general, water used for this purpose is of intermediate quality (non-potable).

2.2 Mineral separation from waste material

At most mines, the raw ore is processed to some extent on site. Ore is usually crushed, then ground to a fine texture (commonly in the 1 µm range). The ground ore may then be mixed with water and a flotation reagent added. This facilitates the entrainment of the mineral grains in a froth, which floats to the surface and may be skimmed. While most of the organic frothing agent is broken down during further beneficiation of the ore concentrate, some remains in the water used for the process, and must be properly stored and disposed of. The waste ore fraction would normally be consigned to tailings after removal of water through settling or centrifugation.

2.3 Leaching and chemical separation

Where beneficiation of ore to a very high level is accomplished on site (for example, to 'product' standard) there will usually be a need for elaborate chemical transformation of the raw materials. Processes frequently used include: leaching (usually with sulphuric acid, though reagents such as ammonia are sometimes used); solvent extraction of the leachate from a water solution to an organic (frequently 'kerosene') phase to assist in metal purification.

2.4 Cleaning mine equipment

Mobile mine equipment, such as excavators and transport vehicles, will usually accumulate ore dust. As this is mineralised material it must normally be removed by washing using water that cannot simply be released to waste. Typically wash water is stored in a special impoundment and is recycled using a pumping mechanism.

2.5 Potable uses

The main uses for high-quality water are for drinking and ablutions of mine personnel. Although water of potable standard is not strictly required for sanitary purposes, it would normally be used in the absence of severe water shortage.

3 Sources of water for mines

3.1 Rainwater stored in constructed reservoirs

Except in the driest regions, rainfall is sufficient to allow for accumulation of water in reservoirs. Typically the impoundment doubles as a sediment trap. This implies that the catchment of the reservoir is largely disturbed ground, either mineralised or not. It would be unusual for such water to be potable, but may be suitable for most other uses.

3.2 Groundwater

Whether mines require groundwater for their operations depends on the availability and reliability of surface sources. Most mines would at least supplement surface supplies with groundwater. This decision may be influenced by factors other than availability, where the withdrawal of large quantities of surface water were seen to deplete environmental flows or otherwise cause ecological damage to wetlands. Few mines would be able to store sufficient rainwater on their sites to meet all their needs. Similarly, most mines would have at least some recourse to bore fields.

3.3 Surface (stream or lake) water

If surface water is available, mines will usually seek to use it at least occasionally, even in areas of high conservation value. However unless water from this source is perennial, mines would wish to have a reliable alternative source.

3.4 Recycling

Virtually all mines recycle water. This in most cases would be due to cost considerations as much as concern for depletion of available resources. Water is often reused through many cycles, and of course this results in progressive deterioration in its quality. Typically such water is diluted or disposed of (for example to tailings) when it is no longer fit for the purpose required, or when Operational Health and Safety considerations make its continued reuse hazardous.

4 Categories of water stored by mines

The following categories of stored water are ordered by (typically) decreasing water quality.

4.1 Potable water

In general, relatively small quantities of potable water are stored on mine sites, usually in holding tanks replenished from borefields or other sources as required.

4.2 Water from sediment traps

Sediment traps range from small bunded structures to dams that may hold hundreds of thousands of cubic metres of water. They typically drain disturbed catchments and are constructed to retard the movement of erosion materials to nearby wetlands, which would increase turbidity to unacceptable levels. The quality of the water contained in sediment traps is variable, but is typically of quite good quality because the disturbed catchment material rarely contains significant mineralisation.

4.3 Water that has incidental contact with mineralised material or plant processes

Most mines are required to impound water (and sediment) that drains from sub-economic ore and the waste rock overburden that accompanies ore bodies. Open-cut mines usually produce a greater volume of waste rock than underground mines. Apart from the sediment produced by weathering and erosion, the water retained in these ponds may contain elevated concentrations of the ore species, as well as ancillary metals.

4.4 Water that has contact with ore stockpiles

Runoff from ore stockpiles can be expected to contain metals and perhaps other species at concentrations far greater than can safely be released to wetlands in raw form, except perhaps at high dilution. Depending on the identity of its constituents, chemical treatment or bioremediation may be required.

4.5 Process water

The processes that release the economic mineral(s) from its ore inevitably mobilise species which remain in depleted water solutions (raffinate) after extraction of the valuable constituents. Other entrained materials, such as organic reagents used as part of the extraction process, will usually also remain in the raffinate. The process stream will also contain large quantities of finely ground ore. The depleted ore particles, apart from containing additional, potentially toxic species that may be released later, would also contribute to turbidity if released. Process water must usually be stored indefinitely in a tailings dam.

5 Water management methods for stored water

5.1 Forced or passive evaporation

Passive evaporation is a viable means of disposal of excess water where total annual evaporation is greater than rainfall. Where this is the case (for example, mean pan evaporation in Jabiru exceeds rainfall by about 1200 mm per year) forced evaporation may not need to be used, except in unusual circumstances.

Some methods of forced evaporation include sprinkling systems that generate a fine spray, and lining the water storage impoundment with black plastic. Forced evaporation is most effective during periods when evaporation rate is greater than precipitation.

5.2 Direct release to streams or lakes

Direct (that is, untreated) release to surface water, whether deliberate, accidental or after rehabilitation has occurred repeatedly in Australia's mining history. Often the ecological consequences to wetlands have been catastrophic, such as at Rum Jungle near Batchelor in the Northern Territory, and the Mount Lyell mine in south-western Tasmania, where copper, lead and acid mine drainage in particular were implicated. Environmental regulations and guidelines now stipulate more rigorously the loads and concentrations of released effluent constituents in most jurisdictions. In practice this means that only relatively benign waste waters, at high dilution, can be released in most circumstances.

5.3 Land irrigation

Land irrigation is a passive means of effluent remediation whereby waste water is pumped or sprayed onto (in most cases) a natural vegetated site. The potentially toxic components of the waste are then removed by various physical and chemical processes. The most important of these processes is adsorption onto soil particles and associated natural organic material. Land irrigation is most effective at removing heavy metals from an effluent stream and these may bind irreversibly to soil components. Heavy metals are the most important toxic constituents of many effluent streams, so land irrigation may dramatically decrease the toxicity of the water that eventually enters wetlands. Land irrigation is not effective at removing the components of waste that contribute to salinity, and may also be ineffective at removing nutrients, depending on the biological character of the irrigation area.

An obvious shortcoming of land irrigation is that the toxic components remain at the irrigated site, and may be remobilised later under some circumstances. This remobilisation may however, be at a slower rate than the original application. In this case, the release of pollutants to wetlands would be spread over a longer time.

Another shortcoming of land irrigation is that the adsorption efficiency of the site may decline progressively as active sites on soils are occupied by contaminants. It is therefore vital that the effectiveness of the irrigation area is continually monitored, to ensure that 'breakthrough' of contaminants is not observed as the ameliorative capacity of the site is exhausted.

5.4 Wetland filtration

Wetland filters are similar in many respects to land irrigation sites, but are different in that they are in most cases permanent wetlands, as opposed to dry land application sites. Wetland filters are primarily used to ameliorate low grade effluents such as urban runoff, where the primary species of concern are nutrients. As such, aquatic plants are usually important components of wetland filters, whether natural or constructed. Nutrients are removed by a number of mechanisms. Phosphorus is removed by adsorption to sediments and by plant uptake, while ammonia and nitrates are removed mainly by plant uptake, although denitrification of nitrate may occur in sediments in some circumstances. For heavy metals and organic compounds, adsorption to sediments and plant uptake may both be significant, though their relative importance has not yet been quantified. This is partly because wetland filters have not been used extensively to remediate heavy metal pollution to date.

Wetland filters suffer the same shortcomings as land irrigation in that they produce localised areas of significantly increased contamination, which may be mobilised later under appropriate conditions. They may also reach their capacity to absorb additional contaminants and must therefore be closely monitored. Where significant plant uptake of effluent components has been demonstrated, harvesting may be necessary to prevent mobilisation during plant senescence.

5.5 Water treatment

Where a mine wishes to dispose of heavily contaminated water, or less contaminated water in a region of particular environmental concern, active water treatment may be necessary. Water treatment may involve chemical or biological remediation, using a batch or flow-through reactor format. In the case of chemical treatment, a common approach is to use metal oxyhydroxides, usually generated *in situ*, to adsorb heavy metal contaminants. Activated carbon and ion exchange resins can be used to remove organic contaminants and salts respectively. Bioremediation takes many forms, including using bacteria to generate metal oxides, or to change the oxidation state of species, usually rendering them insoluble and therefore much less toxic. Sulphate-reducing bacteria can be used to produce sulphide from sulphate (in acid mine drainage for example). This process also forms alkali, so performs the dual role of fixing metals as insoluble sulphides and helping to neutralise the acid.

6 Case study: Water management at Ranger uranium mine

A map of the Ranger uranium mine site is given in figure 1. This shows the stream system in the vicinity of the mine and the areas dedicated to passive amelioration of chemical indicators before effluent water leaves the lease area.

6.1 The Ranger extraction circuit

The Ranger milling operation refines the raw uranium ore to the stage of isotopically unenriched high purity oxide (U_3O_8) which is further treated overseas to reactor-suitable material. The beneficiation process at Ranger uses an acid leaching technique to separate uranium from gangue materials (waste). It does not separate minerals using flotation reagents. The detailed steps in the extraction procedure are described below. They are derived from information provided by ERA (RUM circa 1987).

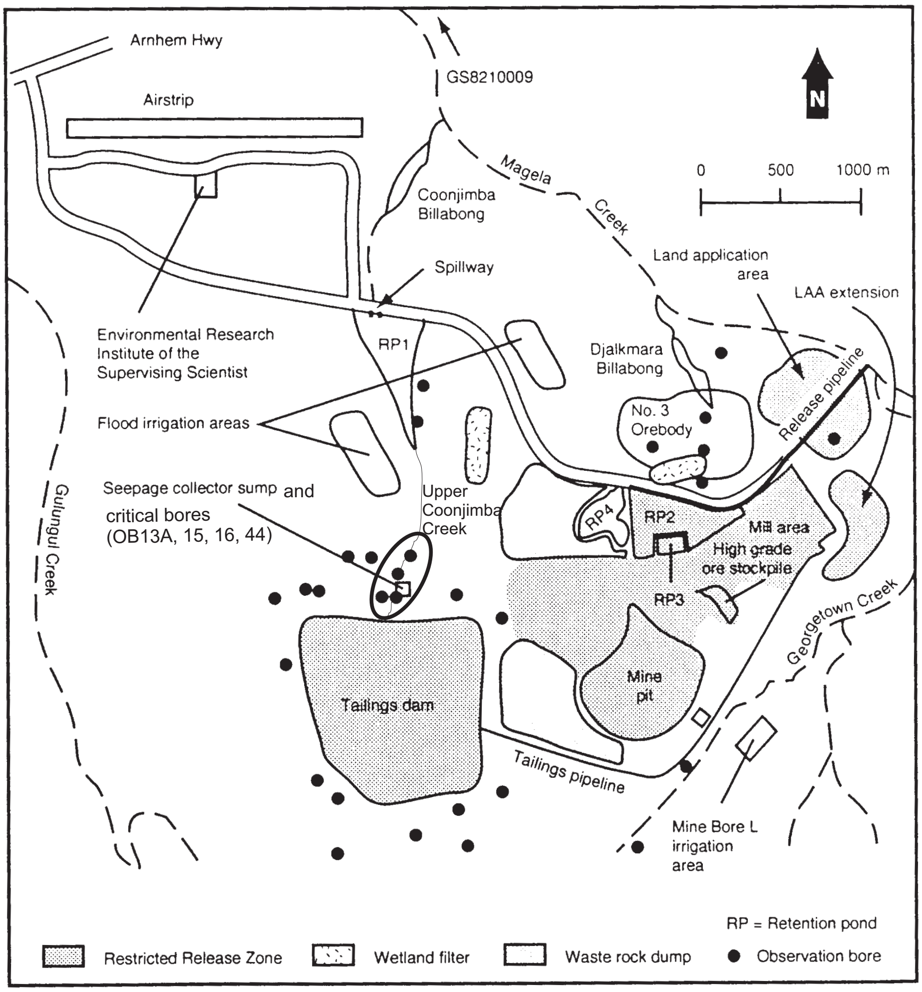

Figure 1 The immediate vicinity of the Ranger uranium mine

6.1.1 Crushing

Ranger uses a three-stage crushing procedure. Ore is separated from waste rock by passing the ore trucks under a radiometric discriminator which measures the radiation yield from the load. This is a direct measure of its uranium content. Rock of ore grade is first crushed using a gyratory crusher followed by a two-stage short-head crusher sequence. The 'fine ore' resulting from crushing has a diameter of less than 2 cm.

6.1.2 Grinding

The fine ore is slurried with water and ground, first in a rod mill, with particles still too large being further ground in a ball mill. After grinding, 80% of the material is finer than 175 µm, and suitable for acid leaching. The grinding process adds about 1 kg of iron per ton of ore by mechanical abrasion of the grinding elements. This iron participates in the oxidation of uranium during leaching.

6.1.3 Acid leaching/oxidation

After thickening of the ground product to about 50% solids, it is leached with sulphuric acid to which is added ground manganese dioxide, the reaction taking about 30 hours. This reagent oxidises the U(IV) present in the ore to soluble U(VI) through the mediation of iron, which acts as a catalyst. The end product of leaching is a slightly acidic (pH~2) solution of U(VI), together with barren particulate matter (tailings).

6.1.4 Clarification

The turbid leach solution is clarified firstly by counter-current decantation, followed by treatment in a thickener and passage at elevated pressure through sand filters. This yields a solution with entrained solids of less than 10 mg/L.

6.1.5 Solvent extraction

The U(VI) solution, which contains many other dissolved species, is purified by solvent extraction. This process involves adding low-volatility kerosene to the water solution (the kerosene floats on the water). The kerosene contains a high molecular weight amine, and an organic modifier. This amine is converted to an organic ammonium ion by the acid remaining in the water solution, and this extracts the uranium as a sulphate complex, forming a salt in the kerosene phase.

6.1.6 Back extraction

Uranium is stripped from the loaded organic phase by extracting it with water containing ammonia, which regenerates the organic amine and transfers the uranium, as uranyl sulphate, to the water phase.

6.1.7 Precipitation

Precipitation of the uranium as ammonium diuranate (yellowcake) is achieved by adding ammonia to the solution until the pH reaches 7.6. The precipitate is thickened to remove excess water, then centrifuged.

6.1.8 Calcination

The final product, U_3O_8 is produced by heating the yellowcake to 700°C in a multihearth furnace. This product is dark green.

A simplified flow chart of the operation is shown in figure 2.

6.2 Sources of water at Ranger

- Retention ponds 1, 2 and 4
- Brockman borefield
- Magela Creek

Water is removed preferentially from RP2 for mill purposes. In most years Ranger has surplus water stored in retention ponds (catchment area ~660 ha; evaporative surface ~150 ha) so the borefield and Magela Creek do not usually need to be drawn upon.

6.3 Water management at Ranger

Water management at Ranger is based on two principles:

- There will almost always be surplus water to dispose of on an annual cycle.
- Movement of water around mine circuits results in quality degradation and more restrictive disposal options.

Disposal options are regulated, generally according to water quality.

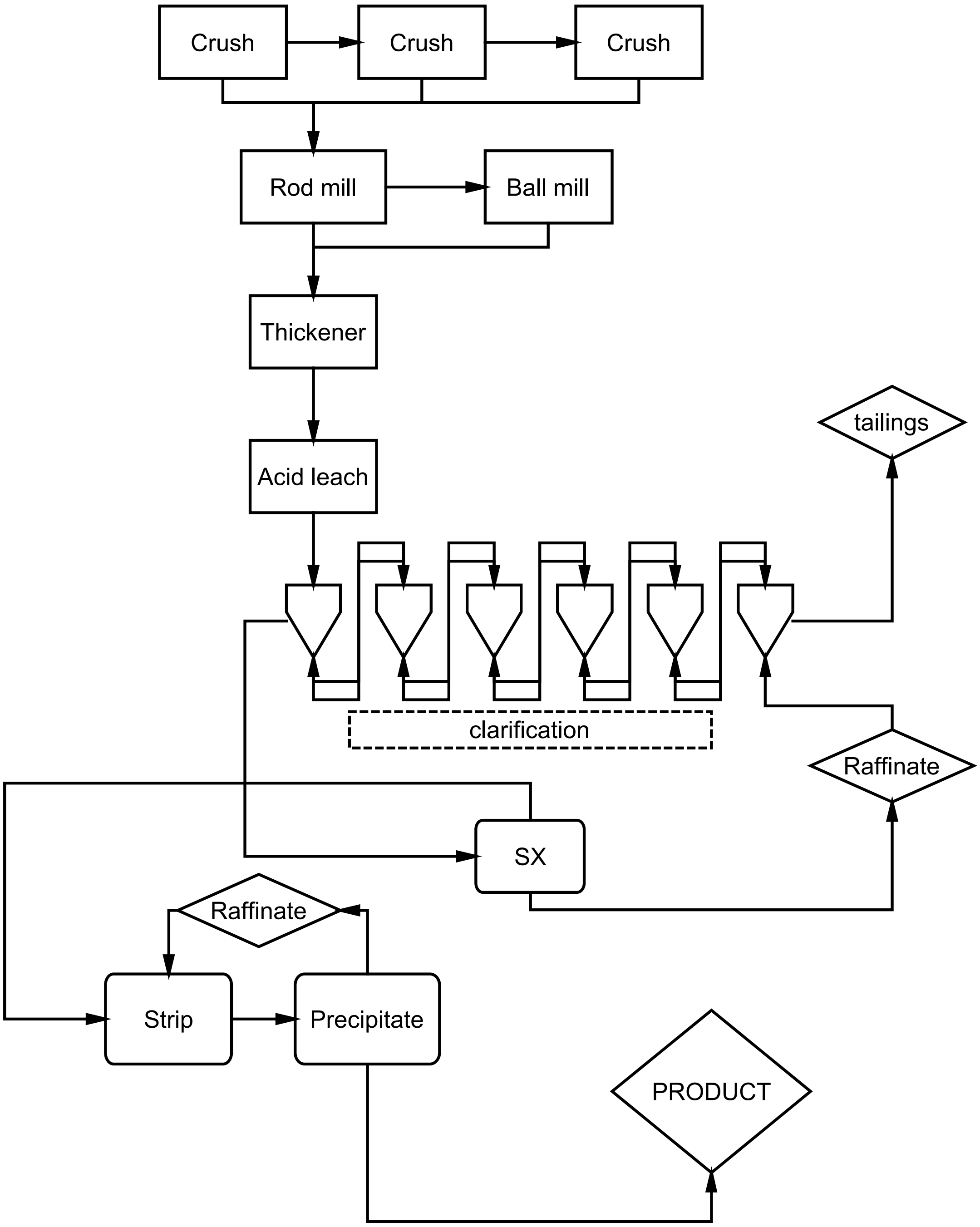

Figure 2 Simplified flow chart of the Ranger Extraction Circuit

6.4 Disposal mechanisms at Ranger

6.4.1 Unrestricted direct release to the environment

Good quality water (usually potable) is released by free egress to Magela Creek. The most important example of this is RP1 water. RP1 was designed as a sediment trap, and although the water it contains has slightly elevated solute concentrations, these do not pose an environmental hazard. RP1, being a relatively mature system, operates as a wetland filter and removes about 10 t of sulphate per year. About 1 000 000 m^3 of water is released from RP1 passively each year.

6.4.2 Restricted direct release to the environment

Water of higher solute content, but low uranium concentration (typified by RP4) can also be released, but regulatory approval must be received, subject to certain hydrological conditions in the creek. Although this water can be released directly to Magela Creek, current practice is to release it into a backflow billabong, which as acts as a wetland filter to remove the small quantity of uranium present.

6.4.3 Release to the environment after passive treatment

Water of similar solute concentration to RP4, but much higher concentrations of uranium and manganese (typified by RP2), can in practice not be released directly to the environment, but must first be 'ameliorated' using either land application, passage through a wetland filter (which removes manganese and most of the uranium), or increasingly, a combination of both.

6.4.4 Water removal by evaporation

Process water is of extremely poor quality. This contains very high concentrations of solutes, some heavy metals and radionuclides, and entrained tailings, and must be completely retained on the mine site, mostly in the tailings dam and Pit 1. The only present means of disposal of this water is by evaporation. Some techniques of enhanced evaporation have been investigated.

6.4.5 Active treatment of waste water

Very Wet seasons (such as 1996–97) can precipitate a water management crisis. This has encouraged ERA to investigate methods of active water quality management. Several water-treatment methods are under consideration, both biotic and abiotic, which would probably involve a reactor-based format. One reactor design of potential interest to ERA is the use of manganese-oxidising bacteria to produce oxide particles of high surface area that can be used to adsorb radionuclides such as uranium and radium. The likely mechanism of adsorption is cation exchange, whereby negatively charged sites on the oxide surface are occupied by positively charged radionuclide ions. ERA is also supporting a project which uses sulphate-reducing bacteria to fix sulphate in effluent streams as insoluble sulphide minerals. This technology may ultimately be deployed in a reactor format.

6.5 A simple water balance at Ranger mine

The total area of 'general catchments' within the Ranger lease is about 6 590 000 m^2. This corresponds to the disturbed area in the immediate vicinity of direct mining and milling operations. It does not include the Pit 3 area which is currently being developed by ERA. The quality of rainwater after contact with these catchments is highly variable; some can only be disposed of by evaporation while some has effectively free egress to Magela Creek.

The following parameters apply to the mine site:

Mean annual rainfall at Jabiru Airport (1971–1997): 1457 mm

Mean annual evaporation at Jabiru Airport (1971–1997): 2625 mm

Of the total 6 590 000 m^2 surface area, about 1 500 000 m^2 is standing water, which has an evaporation coefficient (based on RP1) of 0.92 (this is the ratio of observed evaporation to that predicted from pan evaporation values). Evaporation from areas not inundated is approximately 0.80 of that predicted from pan evaporation (based on the RP1 catchment) while they are wet. The catchment of RP1, net of the pond, (2 100 000 m^2) is vegetated and thus has greater water retentive properties (and hence greater evapotranspiration) than the unvegetated areas of the site, but will suffice for this example. It is assumed that water evaporates from ponds all year, but from land areas only during December–April, when they are wet. The mean evaporation from December–April inclusive is 930 mm.

In an average year, approximately:

$$6\ 590\ 000 \times 1.457 = 9\ 600\ 000\ m^3$$

of rain falls on the Ranger site, of which about 930 000 m^3 flows over the RP1 weir.

Evaporation from standing water is:

$$1\ 500\ 000 \times 2.625 \times 0.92 = 3\ 620\ 000\ m^3$$

Evaporation from 'dry' areas is:

$$5\ 090\ 000 \times 0.93 \times 0.80 = 3\ 900\ 000\ m^3$$

Therefore the mean loss of water from the Ranger site is:

$$930\ 000 + 3\ 620\ 000 + 3\ 900\ 000 = 8\ 450\ 000\ m^3$$

This leaves about 1 000 000 m^3 of surplus water, which is disposed of by a variety of land application methods, augmented by direct release in most years. Some water is also lost by seepage from the various impoundments though this is relatively minor.

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Tourism and fishing in Kakadu National Park

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1 Contemporary historical overview

The size of Kakadu National Park is such that different regions experienced differing historical processes. The following information relates particularly to the north eastern sector of the Park.

Until the beginning of the 1970s the Alligator Rivers Region (ARR) was one of Australia's most poorly known regions. Following failed attempts at resettling army personnel after the two World Wars, the region slumped into a quiet existence populated almost exclusively by the traditional Aboriginal people of west Arnhem Land. Recognition of Aboriginal occupancy of the area goes back a long way. In addition to the establishment of Arnhem Land in 1931, the Woolwonga Aboriginal Reserve, centred on Nourlangie Camp in Kakadu, was established in 1936.

In 1965 the then Reserves Board of the Department of the Northern Territory (the precursor of the Parks and Wildlife Commission of the Northern Territory) proposed a national park in the region. So impressive was the landscape that Mr Joe Fisher, an early mining prospector, lent weight to the concept of several small parks being proclaimed. Indeed it was the activities of mineral prospectors that first uncovered the presence of uranium, initially in modest quantities in the South Alligator River catchment, and later the large reserves of uranium ore under the northern sector of the ARR. These northern discoveries were of such note that the Commonwealth set up a multidisciplinary study designed to examine a wide range of issues which were poised to profoundly affect the future of the region. Accordingly, specialists in the fields of mining, anthropology, archaeology, zoology, pastoralism and national parks combed the region as part of a major and concentrated resource inquiry named the Alligator Rivers Region Environmental Fact Finding Study.

2 Tourism then

Prior to the mid 1970s, limited access to the Park area and the perceived boring nature of the lowland forests served to direct 'tourists' to the wetlands, with a few visiting the art sites at Ubirr, Nourlangie and Deaf Adder Valley. Then, as today, the real ecological 'action' in the region was on the floodplains and in the billabongs. In addition to spectacular scenery and relative ease of travel, on the fringes of the plains, 'tourists' could easily satisfy their blood

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[*] Text of paper adapted from transcript, July 1997

lust by shooting pigs and ducks, catch piles of barra and have a cool-off swim in the rivers and billabongs.

From 1958 till the early 1970s some organised commercial tourism was taking place in the Jim Jim area. Safari camps at Patonga, Nourlangie Camp and Miurella Park were the bases for big game hunting in the region. Patrons flew into these localities from Europe, America and elsewhere in Australia in search of the biggest set of buffalo horns or the largest crocodile skin. Local Aboriginal people were employed as backup marksmen and trackers in these pursuits. Other recreational activities based at these safari camps were wild boar hunting and barramundi fishing.

Buffalo were a common vertebrate feature but were classified as stock and the bread and butter beast on the pastoral properties of Mudginberri and Munmarlary. Poaching of buffalo by pet meat shooters and barramundi by illegal gill-netters was common practice in the late 1960s and early 1970s. Saltwater crocodiles were rare in the area, having been hunted to near extinction. Saltwater crocodiles became a protected species in 1971.

In 1972, the Alligator Rivers Wildlife Sanctuary was declared under Commonwealth Department of Northern Territory legislation. This was to become the nucleus and first stage of Kakadu in 1979. The role of the first five Alligator Rivers Rangers, appointed in 1972–73, was much to do with chasing and catching these hard core and usually aggressive poachers.

In concert with the push for mining, land rights and the declaration of the Park, the construction of the Arnhem Highway, which was completed in 1974, was the conduit to increased tourism in the area. Also feeding this growth was the publication in 1973 of the results of the Alligator Rivers Fact Finding Study, which began to catalogue the extraordinary richness of the mineral, natural and cultural assets of the region.

Government-initiated public exposure during the late 1970s featured natural values, especially wildlife and landscapes. A major media push by the then Australian National Parks and Wildlife Service was designed to solicit support for the declaration of Kakadu National Park by Federal Parliamentarians. This extensive and successful campaign featured beautiful imagery of the region which, in no small way, captured the imagination of many Australians.

During the early 1980s, sudden and prominent media exposure highlighted the national debate concerning mining, conservation, land rights and states' rights issues. This barrage of front page controversy intellectualised tourism in the Alligator Rivers. Visitors were very much interested in these debates as well as the beauty of the region. This was exemplified by the arrival of people carrying cameras rather than rifles. Growth in tourism was proportional with the national media interest in the region. People were excited at the prospect of visiting a remote area only just beginning to give up its secrets.

3 Tourism today

Tourism in Kakadu today is multi-faceted with important seasonal variability. Not only does the season affect access and things to do, but it also changes the type of visitor. A 1993 survey indicated that during the Dry season 67% of all visitors were from interstate in Australia, with only 28% being from overseas. During the wet this ratio was reversed, with 64% being from overseas whilst a modest 22% came from interstate. The same survey indicated that people came primarily to see spectacular wilderness landscapes. Other important reasons to visit were to see wildlife and Aboriginal rock art. In 1993 less than 20% came primarily to catch fish.

Visitor numbers to Kakadu in 1996 were about 220 000. This number represents a continued levelling off, or decline, in contrast to the dramatic rise in visitor numbers experienced in the mid to late 1980s.

Until 1989 the natural environment was promoted as being the jewel in Kakadu's crown. In that year the Kakadu Board of Management, with an Aboriginal majority, was formed. Since that time the cultural values of the Park have taken precedence in promotion strategies. The emphasis on the indigenous culture of the Park is reflected in the 1996 draft of the 4^{th} Kakadu Plan of Management.

The wetlands of Kakadu are inscribed on the Ramsar list of Wetlands of International Importance. In recognition of the importance of these wetlands, the Park offers 19 discrete destinations which principally interpret this landform. A further 4 localities include the wetlands as a secondary message. Feature tourism activities in the wetland environment in the Park include two boat cruises, one viewing platform and several nature trails. The Bowali Visitor Centre and the Warradjan Aboriginal Culture Centre emphasise the significance of the wetlands both from the points of view of a tourism wildlife extravaganza and as a resource rich homeland for Aboriginal traditional owners.

The establishment of tourist facilities within the Park have been achieved through a joint management process involving the Aboriginal owners and Parks Australia. The Mamukala viewing platform and nature trail provides a case study. The completion of the Arnhem Highway in 1974 provided rapid, all-weather access to productive floodplains. This access was valued by local Aboriginal hunters as well as the parks service. Both parties wished to gain access to the Mamukala area via the nearby Arnhem Highway. Bipartisan use of the area was not possible as much of this Aboriginal activity involved hunting geese with shotguns and therefore public safety was a paramount consideration. In 1986, Parks Australia initiated negotiations with Aboriginal owners and residents. An agreement was struck. Aboriginal traditional owners accepted the exclusive use of the Mamukala area by tourists in exchange for another wetland to the north of the highway. Parks Australia agreed to zone this northern wetland exclusively for their use. This agreement has successfully endured since 1987.

4 Recreational fishing

Recreational fishing in Kakadu is almost a single species exercise. Apart from barramundi there is some limited pursuit of thread-finned salmon, Jew fish and miscellaneous reef-fish offshore. There is also some minor interest in catching Saratoga on flys. The prime season for barramundi fishing in the Park is the March to May period, when fish can be caught in good numbers along the edges of floodplain gutters which drain the plains into the South Alligator and East Alligator Rivers. Closed water (billabong) fishing is popular all year and fish can commonly be caught in more than 13 important and discrete water bodies.

All nets, other than landing and mosquito nets, are banned in the Park as is the use of live bait. Crab pots are also a banned item, effectively making all types of crabbing illegal. Fishing upstream of the Kakadu Highway is prohibited with the exception of Muirella Park and Sandy Billabong on Nourlangie Creek. The entire catchment of the West Alligator River is closed to all fishing thus providing one complete river system without any fishing pressure.

Aboriginal people are enthusiastic anglers who generally use less sophisticated tackle than that carried by non-Aboriginal anglers. The traditional palate also enjoys a wider range of table fish, including such species as Saratoga (commonly speared), most species of grunters, Salmon and Eel-tailed Catfish, Sleepy Cod and river sharks.

During the past two decades recreational fishing was a more significant activity in relative terms than it is today. The change has not been due to a withering of interest in fishing, but due to the mass arrival of commercial tourism carrying people who either do not have the time or the interest to fish. Despite the relatively small numbers of visitors fishing, this group of park users are enthusiastic and vocal about their sport.

Park management and the Aboriginal traditional owners recognise recreational fishing as a legitimate activity in the Park. At the same time Parks Australia and the Board of Management recognise the need to manage recreational fishing in a way which is commensurate with the philosophy and objectives of a national park. It is for these reasons that commercial fishing was progressively phased out of Kakadu, ending in the late 1980s.

The changes proposed to fishing in the draft of 4th Kakadu Plan of Management also reflect park management philosophies and have proven to be highly controversial. Draft proposals include:

- A ban on fishing in the East Alligator River upstream of the upstream boat ramp.
- Access down the South and East Alligator Rivers to be regulated by permits.
- A bag limit of two Barramundi per person per day.
- A ban on fishing competitions.
- A review of fishing activities on Yellow Water.

Numerous public submissions as well as direct representations concerning angling were made to the Board. Many respondents were disconcerted to find that *any* fishing is allowed in Kakadu. They argue that *all* the wildlife should be protected in national parks. These people would argue that the more than $1.5 million dollars that Parks Australia has committed to boat ramps and fish cleaning facilities for anglers has been misspent. However, the overwhelming number of public submissions argued strongly for the easing of current restrictions on fishing in Kakadu or at least a maintenance of the status quo. As a result of this public response the Board has devoted considerable time to the issue of recreational fishing and has fully explored all options. The results of the Board's deliberations will be made clear with the release of the 4th Kakadu National Park Plan of Management (released in March 1999 – Kakadu Board of Management and Parks Australia 1998).

5 Issues affecting tourism and fishing on the wetlands of Kakadu

Tourism on wetlands can pose environmental problems which warrant investigation. Several examples and titles of associated studies are listed below.

1. Dry season traffic visiting Twin Falls must cross the upper reaches of Jim Jim Creek. This results in a turbidity problem which persists for a kilometre downstream. A study entitled 'Effects of suspended solids on stream biota downstream of a road crossing on Jim Jim Creek, Kakadu National Park' has recently been completed by ***eriss*** (Stowar et al 1997).
2. An analysis of the environmental, social and economic compromise options for sustainable operation of a tour boat venture in Kakadu National Park was conducted by CSIRO and the Northern Territory University (Braithwaite et al 1996).
3. A study of the impact of recreational angling on numbers of barramundi, entitled 'An assessment of the Barramundi and Saratoga population of Yellow Water Billabong,

Kakadu National Park, 1995 and 1996' was conducted by the Fisheries Division of the Northern Territory Department of Primary Industry and Fisheries (Griffin 1996).

Other management issues include (but are not limited to):

- The threat of the spread of weed seeds on vehicles and machines such as those driven into the Park by tourists, earth moving contractors, pig contractors and others.
- Soil erosion associated with the use of unsealed roads and tracks.
- Prescribed burning and management of late season wildfires. This can be complicated by the presence of campers situated on unburnt floodplain grasses.
- Late season wildfires originating from lightning strikes and other sources.
- Safety issues such as interactions between anglers and crocodiles and boating safety in hazardous tidal rivers.

6 The future

The future of tourism depends in no small part on how other management issues in Kakadu are dealt with, including:

- Protection of Aboriginal land owners rights and interests on their land.
- The proliferation of weeds such as para grass. The arrival of new weeds such as Gamba grass, Mission grass, Aleman grass and Humidicola.
- Containment of *Mimosa pigra* and feral pigs.
- The long term future of buffalo.
- Burning floodplains the 'right way' in a changed environment.
- Perhaps most importantly, the imminent arrival of *Bufo marinus* (cane toad).

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Weed management on wetlands of Australia's Top End

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Abstract

Weeds (plant species growing where they are not wanted) are spreading faster than they can be controlled in Australia. Despite this, new plants with the potential to become weeds are continuing to be introduced into the country. Northern Territory wetlands are relatively free of weeds, but are intrinsically prone to weed invasion, and this is particularly so for the vast Top End floodplains.

Top End wetlands represent an important part of Australia's biodiversity and are very important culturally for Aboriginal people. Weed invasions often have the effect of replacing the varied native vegetation of the floodplains with an extensive monoculture. Consequently, in areas of weed invasion, there is a massive reduction in biodiversity.

This paper describes some ecological and socio-economic reasons for the vulnerability of Top End floodplains to the invasion by weeds and makes suggestions on ways of improving the management of the weed threat.

1 Introduction

Top End wetlands are some of the most extensive and inaccessible in the country and are generally in reasonably 'good' condition (Storrs & Finlayson 1997). These wetlands include seagrass beds, salt marshes and mangrove swamps in addition to the large, seasonally inundated, freshwater floodplains and their associated seasonal or permanent waterbodies. Vast floodplains, especially in the north-west corner of the Territory that receives the most rain, are associated with the major river systems of the Top End (Storrs & Finlayson 1997).

It is the floodplains that I will concentrate on in this paper. They are, arguably, the most biologically significant of all the wetland types and are a focus of human activity. There are about 10 000 sq km of floodplains in the Top End and one of their greatest immediate threats is invasion by weeds (Storrs & Finlayson 1997).

Top End wetlands represent an important part of Australia's biodiversity and are a source of traditional foods and medicines for Aboriginal people. Aboriginal people continue to be reliant on the natural environment for both their spiritual and physical well-being (Pearce et al 1996). Practices such as hunting and foraging have an important place in contemporary Aboriginal life and wetlands are a focus of this activity (Russell-Smith et al 1997).

In the Top End, floodplains undergo dramatic seasonal changes in water depth – from completely dry to depths of several metres in the Wet season. The water is warm to hot and nutrient concentrations vary seasonally, though generally are not particularly high (Walker & Tyler 1984). However, plant productivity is very high, particularly during the Wet season (Finlayson 1988). It is interesting to note that the flora is neither particularly diverse nor unique and species of plants found on floodplains are largely cosmopolitan. However, the outstanding feature of the floodplain vegetation is its seasonal variation in floristic composition (Sanderson et al 1983, Finlayson et al 1989, Rea & Ganf 1994). This extreme seasonal variation of habitats, together with the high productivity of plants leads to very high numbers of animals particularly birds, fish, mammals and crocodiles (Finlayson et al 1988, Rea & Storrs 1999).

2 What is a weed?

A weed is a plant that is growing where it is not wanted (Cowie & Werner 1988). In the Top End, some plants are considered weeds by all land users (eg mimosa and salvinia), while other plants (eg introduced pasture grasses) are considered weeds by some land users (tourism operators, conservationists, anglers), but not by others (eg pastoralists) (Rea & Storrs 1999).

3 The weeds of concern

Throughout Australia weeds are spreading faster than they can be controlled and plant introductions to Australia are likely to occur with increasing frequency (Rea & Storrs 1999). Talking in species numbers, the Northern Territory is relatively free of weeds, with only 5–6% of its flora listed as alien (Humphries et al 1991). This compares favourably to an Australian average of 18% (WM Lonsdale pers comm). Reasons for the low percentage of weed species might include limited agricultural development, low population densities (Humphries et al 1991), seasonal aridity (Usher 1988), and the low fertility of many northern Australian soils (Cowie & Werner 1993).

Low population densities and limited agricultural development add to the common perception that the ecological condition of Top End wetlands is pristine. However, the invasion of feral animals and improved vehicle access followed by pastoralists and other wetland users has often been associated with the invasion of weeds (Storrs & Finlayson 1997).

There are a number of weed species currently threatening Top End wetlands. The three most invasive species are the spiny central American shrub *Mimosa pigra* (mimosa) (Lonsdale et al 1995), the free-floating South American aquatic fern *Salvinia molesta* (salvinia) (Storrs & Julien 1996) and the African pasture grass *Brachiaria mutica* (para grass) (Smith 1995).

In neighbouring savanna woodland (lowland) areas the major invasive weeds are tall, vigorous, perennial grasses such as *Pennisetum polystaschion* (mission grass) and *Andropogon gayanus* (gamba grass). These introduced grasses alter fire regimes by increasing the number of hot, late Dry season fires. Over time, the number of trees are reduced resulting in a change from woodland into grassland (Smith 1995).

4 The weed threat

Weeds have the effect of replacing the floristic, spatial and temporal variation (that are so important for maintaining diversity) with uniformity (Rea & Storrs 1999). Consequently there is a massive reduction in biodiversity.

It is a basic principle of weed management that weeds invade areas that have been disturbed. The more prolonged, repeated or intense the disturbance the more weeds are likely to invade (Hobbs 1991). Apart from the continuous colonisation and retreat of native species due to the seasonal changes in water depth, the floodplains are also prone to fire, wind storms and cyclones. Thus Top End floodplains are subject to a high level of natural disturbance making them intrinsically susceptible to weed invasion (Rea & Storrs 1999).

It is something of a paradox then that it is the extremely dynamic nature of the Top End wetlands that creates their biodiversity, but also makes them susceptible to weed invasion. If this is not enough, non-Aboriginal people have introduced foreign disturbances to the system. Until recently, the main disturbance was the Asian water buffalo (*Bubalus bubalis*), a large feral animal.

Buffalo escaped the first ill-fated European settlements in the north around 150 years ago. By the late 1800s the buffalo population supported a large hide industry that lasted through to the 1950s. In 1985 the feral buffalo population in the Top End was estimated to be 341 406, about the same size as the domestic cattle herd, with densities on floodplains exceeding 7 animals/km^2 (Bayliss & Yeomans 1989). Damage to the wetlands was substantial with large areas denuded of vegetation and levees broken down, allowing premature drainage and saltwater intrusion (Finlayson et al 1998).

During the 1980s numbers of buffalo were reduced to low levels mainly as a result of the Commonwealth's Brucellosis and Tuberculosis Eradication Campaign (BTEC). Following buffalo removal, the recovery of vegetation and amelioration of land degradation has been dramatic (East 1990, Skeat et al 1996). However, during this period of large scale disturbance many weed species were able to colonise. Further, disturbance by feral animals remains a problem because as the buffalo population decreased, the pig population increased. After the removal of buffalo at CSIRO's experimental station in Kakadu National Park, pig numbers were observed to double (Corbett 1995). The absence of effective control measures for pigs and associated wetland disturbance is cause for concern.

Even intensively managed conservation areas are at risk of weed invasion. The number of alien plants in Kakadu National Park has increased at the rate of 1.6 species per year since 1948 (Cowie & Werner 1993), and this trend is expected to continue as a result of disturbance through increased tourism and development. In their survey of Kakadu National Park Cowie & Werner (1988) found that most of the naturalised alien species were associated with human activity such as roadways, borrow pits, settlements, campgrounds and other disturbed areas, but in addition, habitats adjacent to floodplains and creeks were also found to be heavily invaded by weeds.

The economy of the Northern Territory is still in a vigorously government-encouraged development phase and is based firmly on exploitation of natural ecosystems and resources. It is often stated that the land uses most capable of integration on the floodplains are conservation, tourism, recreation, commercial wildlife harvesting, and non-intensive pastoralism (Whitehead et al 1990). However, the Northern Territory Government places great emphasis on agriculture with some agencies seeing intensification of pastoral activities as a priority. This is even though expenditure by tourists is four times the gross value of the pastoral industry (Whitehead et al 1990) and introduced pasture grasses can have a profound effect on the tourism industry by decreasing the wildlife visitors come to see (Lonsdale 1994).

Para grass, which has been used by the pastoral industry for many years, has shown a great capacity to invade wetland areas, but is still being introduced to new sites with government encouragement (Rea & Storrs 1999). Also worrying to wetland managers, is that the Northern Territory Government is encouraging the use of two other improved pasture grasses from South America, *Echinocloa polystachya* (aleman grass) and *Hymenachne amplexicaulis* (olive hymenachne) (Lemcke 1996). These species have been shown in Queensland to smother native vegetation by forming dense and extensive monospecific stands (Clarkson 1995). Both grow in deeper water than para grass, and olive hymenachne, in particular, is a prolific seeder. Currently there is a moratorium on their use in Queensland. Continued introduction in the Northern Territory ignores advice about their weedy potential and flies in the face of agreements to which the Northern Territory Government is a signatory (Rea & Storrs 1999).

5 Strategic weed management

Expansive natural areas combined with small human populations necessitates a strategic approach to tackling the weed issue. The Northern Territory Government has recently developed a weed management strategy (Northern Territory Government 1996) that calls for government to work with landholders and land managers to plan and implement weed management.

A weed management *strategy* entails careful planning and directing the large-scale, long-term operations of a weed management program on a catchment basis (Moody & Mack 1988). Area management rather than species management should be the focus. The philosophy of any weeds management strategy should be to establish why weeds are present and address those causes, rather than killing weeds *per se*. Storrs and Lonsdale (1995) and Storrs et al (1996) present a series of steps that should be addressed in a weed management strategy. These are discussed below.

5.1 Prevention

One of the most powerful weapons against weed incursions is prevention. In Australia it is often the case that weeds are allowed to invade. Plants that have become weedy were, on most occasions, introduced intentionally for other purposes (Panetta 1993). Mimosa, salvinia and 'improved' pasture grasses are all deliberate introductions that have become major environmental weeds.

Ecological Risk Assessment should be mandatory for all proposed plant introductions to Australia or between Australian biogeographic regions. Controlling importation can also cover intrinsic measures such as quarantining of areas and providing stock and vehicle wash-down facilities. Large areas of the Top End, such as Arnhem Land, are free of many invasive species and the desire would be to keep them that way. Education and awareness programs would help in the establishment of changes to current management practices, as would effective liaison and cooperation between agencies.

5.2 Surveillance and early intervention

Surveillance and early intervention is another powerful weapon against weed invasion. There is a need to identify sites at risk, which are generally areas of high disturbance through natural, human or feral animal activity. Rangers and others need to be trained in the identification of weed species and programs need to be developed to routinely survey high risk sites. The value of early intervention was highlighted at Maningrida in the early 1990s when a senior Aboriginal land owner recognised mimosa from a Northern Territory Government poster. He was able to lead authorities to the 0.3 ha plot which was swiftly dealt with.

5.3 Identify habitats that are prone to invasion

In the Top End, wetlands and riparian systems are the natural areas most prone to weed invasion. In fact, all the critical (highly invasive) weed species identified by Humphries et al (1991) are either restricted to floodplain habitats or form their most dense infestations along water courses. Emphasis should therefore be placed on weed management of these habitats.

5.4 Decreasing an area's susceptibility to invasion

There is a need to minimise disturbance and rehabilitate disturbed areas (Hobbs & Huenneke 1992). Developmental activities such as road building should be undertaken in a way to minimise impacts on the environment. There is also a need for a coordinated approach to the control of feral animals. In Arnhem Land, buffalo were largely disease free so BTEC control in this area was limited. Pig control is largely *ad hoc* and ineffective. Another important aspect of decreasing an area's susceptibility to weed invasion is to rehabilitate disturbed areas using competitive native species.

5.5 Managing existing weeds

Invasive weeds may already exist in a region. A prerequisite for a weed management program is a detailed survey of the area to highlight the critical invasive species and the key parts of the landscape they threaten, and to prioritise resources accordingly.

It is necessary to develop a weed management structure to coordinate such activities. Physical, chemical and biological control, the manipulation of fire regimes and promoting native plants; all should play a part. The work might involve a species specific approach using biological and chemical control for highly invasive species but also, as far as possible, habitat management using a range of techniques such as feral animal control, visitor and fire management and the revegetation of disturbed areas (Storrs 1996). This work should include Ecological Risk Assessment of the impacts of control measures such as the use of herbicides.

6 Development of a weed management strategy

A weed management strategy for a specific locality should be integrated with the Northern Territory Weeds Management Strategy (Northern Territory Government 1996) and the National Weeds Strategy (Commonwealth of Australia 1997). In developing a weed management strategy for Kakadu National Park (Storrs 1996) the following steps were taken:

6.1 Research phase

A literature review of environmental weed management in Australia and elsewhere was used to determine the current state of knowledge and identify objectives.

6.2 Consultation phase

Meetings were held with Aboriginal traditional owners, rangers, representatives of Aboriginal associations, government agencies, the tourism industry and weed control professionals. These consultations determined the main issues, needs and priorities in regard to weed management in Kakadu National Park.

6.3 Draft overview paper

Next a draft overview paper was prepared. This developed a conceptual framework for weed management and covered:

1. Main sites of weed infestation in Kakadu National Park and the prioritisation of major weed species;
2. Responsibilities and relationships between different organisations involved in weed control;
3. Current weed management programs;

4 Habitat management objectives such as the minimisation of disturbance and the rehabilitation and revegetation of disturbed sites;

5 Strategies for preventing the introduction of new weeds;

6 Procedures for early intervention in cases of new weed incursions;

7 Training, staffing, resource and research needs;

8 Performance indicators.

6.4 Further consultation and development of the strategy

The draft overview paper was circulated widely for comment and further consultation undertaken. The extensive consultation was undertaken to embody the state of current knowledge and opinion within the strategy and to ensure ownership of and support for the document and directions. These actions combined provided the basis for the strategy.

7 Conclusion

Wetlands of the Top End are relatively pristine, however the invasion of weeds is and will continue to be a real threat. The vast size of the Top End and the relatively small population mean that it is necessary to take a strategic approach to tackling the weed issue. Once the planning process is completed, it is necessary for government, conservation agencies and land owners to work together and provide the resources to ensure that strategic weed management can be carried out.

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The management of *Salvinia molesta* in Kakadu National Park, Northern Territory, Australia

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Abstract

Kakadu National Park, listed as a World Heritage Area, is the jewel in the crown of Environment Australia's national parks. Kakadu National Park is dominated by two major river systems, the East Alligator and South Alligator Rivers and their associated tributaries and floodplains. These huge wetlands are very important to the ecology of the area and played a large part in securing the park's World Heritage Listing. They are also listed by the Ramsar Convention as 'Wetlands of International Importance'.

The rampant floating aquatic weed, *Salvinia molesta* (salvinia), was discovered in Kakadu National Park in 1983. It was decided to rely on biological control rather than attempt to eradicate the weed due to the large extent of the existing infestation and successes with the biological control agent, a weevil, elsewhere in Australia. Although the weevil appeared to give good control in early years, there was a huge build-up in salvinia in the late 1980s that resulted in the complete coverage of most billabongs in the Magela Creek system for more than 2 years. This build-up prompted the Australian National Parks and Wildlife Service (now Parks Australia) to contract the CSIRO Division of Entomology to investigate the situation and suggest measures to improve control.

This paper presents a background to the salvinia problem and an account of salvinia management in Kakadu National Park.

1 Introduction

Compared with the rest of Australia, Kakadu National Park has relatively few weed species (Storrs & Lonsdale 1995, Storrs 1996). However it does have a number of invasive weeds (ANPWS 1991), one of the most notable being the aquatic weed *Salvinia molesta* (salvinia) (Holm et al 1977, Mitchell 1978). Salvinia was first reported in Australia in 1952 but was not discovered in Kakadu National Park until 1983 (Finlayson 1984a).

Salvinia is a floating fern that is native to a restricted area in south-east Brazil; a sub-tropical zone at a latitude that equates with the area from northern New South Wales to southern Queensland in Australia. It is believed that salvinia was originally exported as an aquarium or pond plant and has since invaded tropical wetlands throughout the world. It is a sterile plant that reproduces vegetatively. Under ideal conditions and away from its natural enemies it has a phenomenal growth rate and can double its dry weight every 2–3 days (Finlayson 1984b) although the fastest growth rate recorded in Kakadu National Park was a doubling of dry weight in 5–7 days (Storrs & Julien 1996).

Chemical and physical methods were initially used in attempts to control salvinia in the Northern Territory and, in a limited number of cases where infestations were well contained, successful eradication was achieved (Miller & Pickering 1988). It is important to note however, that review papers from the late 1970s state that, despite considerable effort to control and eradicate salvinia, no single satisfactory solution had emerged (Finlayson & Mitchell 1982).

2 Biological control of *Salvinia molesta*

In the early 1980s, CSIRO Division of Entomology had major successes with a biological control agent on infestations in Queensland (Room et al 1981). The agent was a small weevil, *Cyrtobagous salviniae*, discovered in the home range of salvinia, in south-east Brazil (Room et al 1981, Calder & Sands 1985). The adult weevil feeds on the new buds preventing growth from that point. However, the real damage is caused by the larvae as they burrow through the rhizome of the plant causing the plant to become friable and waterlogged to the point where it eventually sinks and drowns (Sands & Schotz 1985).

In trials in Queensland, the level of control by the weevil was dramatic. On a 400 ha infestation on Lake Moondarra, weevils reduced the infestation to just 4 ha in 18 months, that is 1% of its former size. In the process the weevils had destroyed 8000 tonnes of salvinia (Room et al 1981). The weevil has since been exported to other areas of the world and has proven to be one of the most successful biological control agents to date (Storrs & Julien 1996).

3 *Salvinia molesta* in Kakadu National Park

In 1983 salvinia was found in the Magela Creek, a tributary of the East Alligator River (Finlayson 1984a). As the salvinia infestation was considered too extensive to eradicate, it was decided to rely on the newly discovered biological control agent (Storrs & Julien 1996).

Weevils were first introduced into the Magela Creek system in late 1983 and further releases were made in 1984/85. Once established, weevils spread and seemed to provide reasonable control in the early years, though evidence for this is anecdotal (Storrs & Julien 1996). In later years (1987–1991) however, control was unsatisfactory with salvinia expanding and completely covering billabongs. Some billabongs were covered for more than two years at a time with a thick layer of salvinia which was subsequently colonised by grasses, sedges and even small trees to form a sudd (Julien 1990, Skeat 1990).

Salvinia is considered detrimental because it can alter aquatic ecosystems and change the distribution of native plants and animals. In Kakadu National Park, it also restricts the use of waterways for food gathering by Aboriginal traditional owners and impacts on recreational fishing and tourism (Storrs & Julien 1996). Despite quarantining the Magela floodplain and undertaking other efforts to prevent the weed spreading in the park, a new infestation was found in 1990 in Nourlangie Creek, a tributary of the South Alligator River. This infestation, though downstream, is very close to the major tourist destination of Yellow Waters (Storrs & Julien 1996). Previously in 1989 an infestation was also found in a tributary of the East Alligator River, nearby in Arnhem Land (CM Finlayson pers comm).

The apparent lack of control in some years by the weevil was unusual and prompted ANPWS (now Parks Australia North) to contract CSIRO to undertake a 3 year research project, starting in July 1991. The project was designed to monitor the environment, the weevil and the weed to determine factors limiting control and to look at ways of improving control (Julien & Storrs 1993, 1996, Storrs & Julien 1996).

4 Results of the CSIRO salvinia project

The weevil population was found to be well distributed throughout the study area; thus there was no need to make any further large-scale introductions. However, the weevil population and associated plant damage were observed to have annual cycles. The numbers of weevils increased dramatically during the early to mid Dry season (May to September), and then rapidly declined shortly afterwards in the late Dry to early Wet season (October to January). During the time of this study the trend was consistent from billabong to billabong although it was not synchronous between billabongs or within billabongs (Storrs & Julien 1996).

The study examined factors such as the effects of high temperature, nutrient availability, changes in water quality and predators and pathogens that may have caused or influenced the decline in weevil numbers (Julien & Storrs 1993). Experiments showed that high temperature had no significant effect on adult weevil survival, fecundity or on egg laying and hatching. Salvinia nutrient analysis suggested that changes in the populations of the weevil were not limited by nutrient availability. Preliminary assessments of water characteristics indicated that when water quality changes occurred, they did not affect all billabongs, whereas weevil populations built up and declined in all billabongs about the same time. Assessments of weevil predators showed that although they were present, numbers were insufficient to contribute to the dramatic population declines observed. No diseases of the weevil were found (Julien & Storrs 1993).

It was concluded that the decline in weevil numbers was due to the severe damage that the weevils did to the weed. The rapidly increasing weevil populations destroyed the quality of the weed to the point in the late Dry season when there were no growing tips left (the food of adult weevils) and all rhizomes were hollowed-out (the food of the weevil larvae). This resulted in very high weevil mortality rates which reduced the populations to low levels (Julien & Storrs 1993).

Wet seasons in the region can be extremely variable and this variability appears to significantly affect the dynamics of biological control of salvinia. The onset of the monsoon can occur over an extended period, or not at all. As well as the timing of the Wet season floods varying, the timing of the weevil population build-up and decline also varies from year to year. The difference in salvinia biomass accumulation from year to year seems to be linked to the timing of crash of the weevil population, coupled with the timing and volume of flooding. The results showed that, in some years little salvinia growth occurred, restricted to a large extent by the action of the weevil whereas, in other years, salvinia biomass increased rapidly, often resulting in complete cover of the billabongs (Storrs & Julien 1996).

Rains of the early Wet season and the initial flooding during each Wet season provides an influx of nutrients to the billabongs and it is hypothesised that there is a consequent high growth potential of salvinia (Storrs & Julien 1996). In a ‘good’ Wet season floods arrive early and the follow-up flood waters dilute the system, decreasing nutrient levels and thus reducing salvinia’s growth potential. In a ‘poor’ Wet season, major floods are slow to arrive allowing ‘a soup’ of relatively nutrient rich waters to remain in the billabongs for some time with a consequent high growth potential for salvinia. If weevil numbers are low at this time this growth potential is achieved. In a ‘poor’ Wet season the nutrient influx can be intensified by ‘fish kills’. The fish kill can take place over a number of days and involve thousands of fish within a billabong. The dead fish quickly decompose releasing nutrients into the system which can assist the growth of salvinia (Storrs & Julien 1996).

During the time of the study, when major floods arrived early in the Wet season the flushing effect, coupled with the fact that weevils had not yet declined to low numbers, meant that the weevils were able to restrict the lower growth potential of the weed. Both populations of the weed and the weevil increased, but the relative abundance was such that the weevil suppressed growth rates, restricted biomass increase and the level of cover by the weed (Storrs & Julien 1996).

Conversely, when floods arrived late, nutrients brought by initial rains stimulated rapid growth in salvinia which continued for some time before any flushing took place. This, coupled with the fact that weevil numbers were extremely low meant that the salvinia increased without restriction. Although weevil numbers started to increase they could not prevent the exponential increase in salvinia biomass. The increase in salvinia peaked, on average, in September. By this time, or shortly afterwards, weevil populations had built up sufficiently to sink the mats, or at least, greatly reduce their biomass. Remnant, heavily-damaged mats were usually flushed out by flood waters during the next Wet season. Occasionally, however, a second or even third poor Wet season occurs and damaged mats are not flushed. Each new season's growth of salvinia and other vegetation supported on the mats, adds to the already high plant biomass and forms a thick sudd. This habitat is much less suitable to the weevil, much less likely to sink and more difficult for average flood waters to remove. Such sudds developed in the Magela system in 1987 and covered billabongs until 1989 when floods removed them during the Wet season of 1989/90 (Storrs & Julien 1996).

5 The prospects for improving control

It must be emphasised that biological control of salvinia is a cyclical process. Further, the CSIRO study showed that there was no benefit to be gained by continuous and repeated introductions of the weevils into areas of the Magela floodplain where the weevil was already established. Even in poor Wet seasons the numbers of weevils released were insufficient to modify the level or timing of damage compared with that caused by existing field populations (Julien & Storrs 1993).

With a better understanding of the relationship between salvinia and the weevil in Kakadu National Park, the situation of inadequate control in late arriving, poor Wet seasons could perhaps be improved by integrating biological and chemical control techniques (Julien & Storrs 1996, Storrs & Julien 1996).

The chemical AF100 had been recommended for use on salvinia in Kakadu National Park by the Commonwealth Environmental Protection Authority. AF100 is a formulation of kerosene and a surfactant called Kemmat which has the effect of breaking the surface tension of the water allowing the weed to sink and drown (Diatloff 1979). Studies conducted on the ecotoxicology of the herbicide spray in Kakadu National Park found it to be relatively benign (Finlayson et al 1994).

During the CSIRO study an integrated trial was conducted that indicated that salvinia cover could indeed be further reduced by spray application of the herbicide. The timing of application was found to be important if resources were to be conserved and minimum herbicide used (Julien & Storrs 1996, Storrs & Julien 1996). The best time for application was found to be immediately after the peak water flow in the Wet season. Application at this time was shown to significantly reduce the recovery rate of salvinia during the following early Dry season and occurred after the biological control agent had reduced the salvinia biomass to its lowest levels. In addition, Wet season water flow through billabongs reduced the toxicological effects of the herbicide (Julien & Storrs 1996, Storrs & Julien 1996).

It is not desirable to introduce large-scale use of chemicals in a World Heritage Park. Rather the situation calls for a light-handed approach; for instance, there was little need for chemical intervention in the Magela system over the years 1992–1998.

6 Conclusion

Salvinia is present in the Kakadu region and is very unlikely to be eradicated. People must learn to live with some level of salvinia. The weevil is certainly contributing to the control of salvinia in Kakadu National Park by restricting growth rates and biomass accumulation, although this occurs in a cyclic manner. This is classical biological control at work.

The outcome of the CSIRO project was to develop a management strategy that would permit the biological control agent to work to its best effect but, when necessary, use herbicides to prevent salvinia biomass accumulation and cover on billabongs. Although we now know a lot more about the dynamics of the weed and weevil populations, a three year study of such a complex and dynamic biological system is a very short time and further data are essential. As further knowledge is gained from monitoring and spraying operations the management strategy can be further refined.

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Fire management and research in Kakadu

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1 Introduction

Fire is one of the major management issues in Kakadu National Park, indeed as it is throughout the Wet-Dry tropics. It is of equal management importance with weeds and feral animals, and of course all three factors interact.

It's important to realise that fire has been part of the landscape for a long, long time. Even before the Aboriginal people arrived, fire was caused by lightning, although the climate and vegetation would have been very different from now. Certainly Aboriginal people have been burning the country for a long time and the vegetation is, on the whole, adapted to fire. The country is burnt much more regularly than in southern Australia and the fire ecology of the monsoonal tropics very different from that of southern Australia. We have regular fires through the savannas which are typically cool compared with those in the southern eucalypt forests. They generally don't get up into the canopy, but tend just to burn the grassy understorey.

The perception of visitors to the Park is that we are burning too much, and that comes from the southern perception of fire and the devastation of events such as Ash Wednesday. It is simply not like that here in Kakadu. It is inevitable that the country will burn every few years or more often – even every year – if we don't manage fire properly. Hence our management strategy is to light fires; that's our major tool for fire management.

2 Aboriginal use of fire

The Aboriginal people use fire for hunting purposes, to drive game; for green pick, to encourage regrowth to bring game into the country; and to clear the country to make travelling easier. In fact they regard burning as 'cleaning up the country'; the country is often regarded as unclean if it is not burnt, so it is part of their culture to burn. There are also spiritual reasons for burning or not burning in certain places. Certainly in some areas of Kakadu National Park, Aboriginal people burn to protect particular resources, for example monsoon rain forests which are rich in foods like yams. They back-burn away from the forest in some parts, although we don't know if that happened in all places. The effect of Aboriginal burning is to produce a mosaic of burnt and unburnt patches early in the year, which creates a diversity of habitat for game and reduces the late Dry season fires which are typically much more intense and widespread if they are not controlled by mosaic burning. It creates fire breaks.

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[*] Adapted from transcript, July 1997

3 Recent fire regimes

During this century, fire regimes have changed considerably from the typical Aboriginal fire regime. In Kakadu this happened largely because the country was de-populated early in the 1900s. There was a drastic reduction in the Aboriginal population, mainly through the introduction of diseases by settlers, but also through people moving off their country to towns and settlements.

So, there were simply not enough people there to continue burning the country. Then pastoralism began in the area and the pastoral managers had different reasons to burn. The country was typically burnt later on in the year.

The population of Aboriginal people has grown since Kakadu National Park was declared, but not to anywhere near pre-European settlement levels. Burning patterns today are not exactly the same as pre-European settlement ones, and burning is now more concentrated around settlements and roads, reflecting changes in movement patterns and methods. This is reasonable, as Aboriginal culture has always been dynamic, never static, and these changes have been adopted into their culture.

4 Fire management

As outlined in the Kakadu National Park Plan of Management, fire management objectives in the Park include:

- To protect life and property within and adjacent to the Park.
- To maintain, as far as practicable, traditional *Bininj* burning regimes within the Park (*Bininj* meaning Aboriginal people).
- To maintain biodiversity.

There is also an aim to promote research into the fire sensitivity of environments, which will enable the identification and protection of sensitive environments.

The challenges to us in our management program are:

- How do we go about maintaining traditional burning patterns and maintenance of biodiversity?
- What is the appropriate regime in each different habitat within the Park that will maintain biodiversity?
- How do we repair the damage from years of inappropriate fire regimes?

The damage from inappropriate fire regimes in the past is reflected in a great proliferation of speargrass, the native *Sorghum* spp. Speargrass is an annual grass and a fire weed which under prolonged, regular, late-Dry season burning occurs in greater densities in the Park – in fact across the Top End – than it naturally would. It is a self-perpetuating process because it is very much promoted by fire, and in turn it promotes fire by increasing the fuel load. All the seeds are in the seed bank before it burns, waiting for next year's rains to come before they germinate.

So having realised the predominance of late season fires from our own observations and also from several satellite imagery studies that were done during the 1980s, the Park decided to adopt a much more strategic and systematic approach to fire management. This largely involves aerial ignition using helicopters, together with strategic burning on the ground, for example around the Jabiru township and infrastructure, fences, Park boundaries, and around sensitive habitats like small patches of monsoon vine forests which are not as resistant to fire as the savanna vegetation. This is the only way that we can simulate traditional burning patterns because, even with all the Park staff and a few hundred Aboriginal residents, we can't do it the way it was done. We simply do not have the same number of people covering the same amount of ground that there were a hundred years ago. We cannot be as accurate when lighting fires from helicopters, but it's the best we can do at the moment. Using this technology we can do early mosaic pattern burning and, hopefully, we will ultimately achieve the same effect as was achieved before by many Aboriginal people travelling over the country.

4.1 Wet season burning

We also have a program of Wet season burning. The aim is to save some country from being burnt during the Dry season, which is not always easy, especially if it is near roads or towns. On dry days in the Wet season the previous year's dead speargrass crop can be burnt, which will kill the new season's young speargrass. As speargrass seeds only last for one year in the soil, you can actually eliminate nearly all of it with a good Wet season burn. In practice, however, the danger is that someone will light up a large patch late in the Dry season and instead of getting a nice Wet season burn, you get another destructive late fire. This has happened often but there has still been considerable success in reducing speargrass throughout the Park.

While overall we have achieved considerable success in changing the fire regime from predominantly large, late fires, to a patchwork of small fires early in the year, we have some way to go with a lot of questions still to be answered. We still have a lot to learn about the effects of different fire regimes on vegetation and fauna, and especially about fire and weed interactions. For example, in the southern part of the Park where we have been doing Wet season burns, the introduced weed *Crotalaria goreensis* seems to love it. It comes up in huge areas and is spreading without our help so it is going to be a major problem there.

We also have more to learn about protecting the relatively fire-sensitive habitats. In general we believe that the fire frequency is still too high, especially in savanna woodlands and forests and the sandstone country.

4.2 Fire-sensitive habitats

In fire research and management, we need to look at the three broad habitat types in the Park:

- lowland open forests and woodlands (the savannas)
- floodplains
- sandstone plateau and escarpment

Obviously there is diversity within those types, but they are the broad categories, each with their own fire and management problems. Generally, the most fire-sensitive communities are the monsoon rainforests, the *Callitris* pine communities and the sandstone heaths. They are all fire-tolerant to a certain extent, but are susceptible to changed regimes. The *Callitris* pine is particularly fire-sensitive and many are being killed by hot fires and are not regenerating, right across northern Australia, from Western Australia to Cape York. The sandstone heath communities are adapted to particular fire regimes, but high frequency, intense, late season fires are very destructive to these habitats. The impacts of hot fires on monsoon forests, which occur in isolated pockets within wetland, lowland and sandstone habitats, range from margin erosion to complete destruction.

4.3 Burning the floodplains

The floodplains are different from the other two broad habitat types, in that often you can't burn early and until a few years ago they were covered with buffalo. It was a completely different system then from what we have now as there simply wasn't the huge biomass of grasses and sedges present. Also the floodplains have particularly drastic weed problems, for example Para grass (*Brachiaria mutica*) in Kakadu and *Mimosa pigra* outside the Park. Grassy weeds such as Para grass are a problem and obviously affect the fire ecology of floodplains. There has not been a lot of research done on floodplain burning and it has been identified as a priority for future research in the Park. Sue Roberts (Braithwaite & Roberts 1995) has studied floodplain burning patterns, and Diane and Kate Lucas (Lucas & Lucas 1993) and Jeremy Russell-Smith et al (1997a) have done a lot of work with traditional owners which probably gives us the best indications for fire management of the wetland areas. Floodplain burning is a fine art and the best practitioners in Kakadu are the Aboriginal custodians.

Aboriginal people practise progressive burning, setting fire to the floodplains as they become dry enough to burn. This reduces species like *Hymenachne acutigluma,* which will otherwise tend to form monocultures and exclude other species, for example lilies, and *Eleocharis* bulbs which are an important resource for Aboriginal people and magpie geese. Research carried out by Peter Whitehead in the Mary River region has shown that burning helps to increase species diversity on the floodplains (Whitehead & McGuffog 1997).

Burning also reduces the humic build-up from the grass cover, which if allowed to build up can cause very slow-burning but high intensity fires in the humic layer. Such fires are unstoppable and will burn entire floodplains, killing turtles in the mud if they are not yet buried deep enough. Sometimes turtles cannot even bury down into the mud if there is a thick humic layer, and instead bury into the grass layer, where they are burnt. Out at Oenpelli there is a lot of Para grass on the floodplain, and Jacob Nayinggul told me that they are digging up the turtles already cooked!

The same hot fires also slice huge *Melaleuca* trees off at the base, killing them. Some believe this is a problem, but others argue that losing the *Melaleuca* trees is a natural course of events following removal of the buffalo. They argue that the *Melaleuca* stands are there as a result of the huge numbers of buffalo present in the past. I don't think that these discussions have appeared in the literature yet. We also face serious problems with hot fires damaging the pockets of monsoon forest that occur on or adjacent to the floodplains. Again, these problems are compounded by the presence of Para grass.

In the past the floodplains were a major focus of activity and quite heavily populated in the Dry season, with people moving around and burning expertly as they went. The nature of progressive burning of the floodplains means that it is labour intensive, and now the population is simply not there in most areas. The major challenge for the park managers is to maintain fire regimes that protect biodiversity and cultural resources with a very limited labour force. We do not possess technology that can replace the presence of people on the floodplains.

5 Fire research

5.1 Munmarlary fire experiment

The lowland savannas are the best studied of the vegetation systems to date, and several major research programs have been conducted in the Park. The earliest was the Munmarlary fire plot experiment, begun in 1972, in which a series of one hectare blocks were treated with four different fire regimes. This experiment is still running now, twenty five years later, except that all but one of the plots were unintentionally burnt this year. It will be interesting to find out where that fire came from – no one is confessing to it! We simply couldn't get any equipment in there before it became accessible after the end of the Wet to create fire breaks or do back-burning in time to stop the plots being burnt.

The Munmarlary experiment results have been written up by Hoare et al (1980) and Bowman et al (1988), and now Jeremy Russell-Smith is in the process of doing a final analysis and documenting the twenty-five year results. Although the experiment was heavily criticised by Lonsdale and Braithwaite (1991) on the basis of its design and analysis, it will prove to be a very useful exercise. Bowman et al (1988) concluded from the 13 year results that soil factors were more important than fire in determining vegetation patterns. The twenty-five year results will be very interesting indeed.

Animal studies done by John Woinarski on birds (Woinarski 1990) and Alan Anderson on ants (Anderson 1991) at Munmarlary, and by Dick Braithwaite on lizards (Braithwaite 1987) elsewhere in Kakadu, clearly show that different animal species have different preferences regarding burning regimes. They recolonise areas at different rates following burning, and cope with different burning intensities. The upshot of that for management is that not only should we aim for a mosaic of burnt and unburnt patches, but we must really aim for a mosaic of patches with different fire histories. Some animals prefer freshly burnt country, others 1–3 years since burning, and others unburnt country. Only a few species prefer completely unburnt country, but there are many species which rely on relatively fire-sensitive habitats like monsoon vine forests.

5.2 Kapalga fire experiment

A major fire experiment on savannas was also conducted by CSIRO at Kapalga. This was a landscape-scale fire experiment conducted for 5 years (1990–1994). Kapalga is a large area between the West Alligator River, South Alligator River, the Arnhem Highway and the coast, and it was divided into twelve compartments, each being a single catchment of 15–20 km^2 in area. Four fire regimes were chosen, each with two replicates: early-burn, late-burn, progressive-burn (burning down the slope as the vegetation dries out) and natural (protecting it from other fires but allowing nature to take its course). It was a multi-disciplinary study with six core projects: nutrients and atmospheric chemistry, temporary stream vegetation and insects, small mammals and vertebrate predators.

Most results are yet to be published from that experiment, although Michael Douglas (Douglas & Lake 1996) provides an insight into temporary stream flora and fauna responses under different fire regimes. Results for several research areas were presented at the recent Bushfires '97 conference (McKaige et al 1997). Most, but not all, of these researchers prescribed early burning, as the Park is now doing, as the best management option for maintaining biodiversity (Anderson 1997, Corbett et al 1997, Griffiths 1997, Williams 1997).

5.3 Wet season burning research

Wet season burning is an important tool for reducing speargrass, and some research has concentrated on this aspect of fire management. Williams and Lane (1996) and Lane and Williams (1997) concluded that late December fires give the best result, assuming that it has started to rain. It means that we should burn in the early Wet season, before the rains really set in. They found an increased abundance of forbs after 1996–97 Wet season burning, a change in the species competition and reduced fuel loads in the following year. Brennan (1997) found an overall reduction in biomass of the understorey layer, but an explosion in the biomass of an array of relatively diminutive grasses and herbs. Preliminary data from the photo monitoring plots (see below) are showing a significant increase in species diversity in sandstone habitats following Wet season burning. Joy Maddison (pers comm) has been monitoring spear grass plots and has found that the sorghum takes approximately 5 years to recover, even in a small plot close to neighbouring areas which are a ready source of seed.

5.4 Remote sensing

5.4.1 LandSat MSS

There is currently a major project underway to construct a fire history for Kakadu National Park, using LandSat Multi-Spectral Scanner (MSS) imagery, from 1980 to the present. This involves obtaining at least three coverages for every Dry season. From 1980–90 these images were mapped manually, but since 1991 they have been mapped using interactive digital techniques. The results show that since 1980, on average, 46% of the lowlands, 28% of the floodplains and 28% of the sandstone country have been burnt annually. There has been a marked change since the mid-1980s from large, late Dry season fires to a lot of small, early Dry season fires. There has also been a marked increase in floodplain burning in the few years since the removal of buffalo. Most of the sandstone country is still being burnt in the late Dry season.

Ground-truthing is important in this exercise. This is done by helicopter, flying transects and taking GPS readings, recording points as burnt or unburnt every thirty seconds in random transects throughout the Park. Ground-truthing is done a few days before the satellite overpass. All the data is stored in the Parks Australia North GIS system, ERMS, which incorporates other GIS coverages such as boundaries and landscape units, vegetation, hydrology and topology. Derived coverages include proximity analysis and frequency of burning. From the ground-truthing, we know that the degree of accuracy in the interpretation of the imagery is over 80%.

Analysis of the GIS data (Russell-Smith et al 1997b) shows that the lowland savanna sites are being burnt on average 3 out of every 5 years, which is significant. The majority of sandstone sites were burnt on average between 0–4 times over the past 15 years, and floodplains between 0–3 times. The medium size of continuously burnt areas has been declining steadily, from over 300 hectares in the early 1980s, to about 60 hectares now, largely because the fires are cooler. As burning is done in the cool part of the year the fires tend to extinguish at night.

There are a few problems with LandSat MSS imagery. For example, cloud cover during the Wet season means that Wet season burning can’t be recorded and small burns are often missed. There are also positional errors of up to 300 metres which mean that you can’t follow the fire history of individual pixels or a single point.

5.4.2 NOAA AVHRR

We are also starting to use NOAA AVHRR imagery which has several advantages; it is free and is flown daily. Unfortunately it has a very low resolution (1 km^2 pixels), so it is without the detail of LandSat MSS imagery. However it has proven to be very useful, having great potential for day to day management of fires.

5.5 Photo monitoring plots

In conjunction with the fire history and fire scar mapping projects, photo monitoring plots have been established throughout Kakadu, including the wetlands (Ryan & Russell-Smith 1995). The plots are 40 by 20 metres with a fixed point for taking photographs. All the trees are tagged and an inventory made of all trees and shrubs. They are divided into size classes, counted, and ground cover is estimated in a series of 1 m^2 quadrats. The site is well described. This study is set up to continue for at least 90 years – the life of the Park lease. It allows us to monitor the responses of a lot of single sites with very accurately known fire histories. The sites are visited twice a year, photographed, and ground-truthed for burning. It involves many Kakadu staff, giving it the advantage of staff ownership of and involvement in the research, and the consequent potential for direct application of the results to management.

5.6 Sandstone habitat research

Similar to the photo monitoring plots are plots that have been established in sandstone habitat (Russell-Smith et al 1998) in the three fire-sensitive communities occurring there; the monsoon forests which are dominated by *Allosyncarpia*, the *Callitris* pine stands, and the sandstone heath vegetation. The big problem with the sandstone areas of Kakadu is that all the western Arnhem Land area across the eastern boundary of the Park is de-populated and is not being managed at all. As a result, huge fires, often with a 100 km front, sweep across the boundary into Kakadu, driven by the south-west winds. One year a fire was traced back to the Ramingining dump, 300 km to the east. This is a very serious management problem because the sandstone communities are species-rich with a very high level of endemism, much higher than in any of the other habitats in Kakadu.

The *Allosyncarpia* forests are currently being eroded at the margins and broken up by hot fires. The heath communities are also at risk. 54% of the sandstone heath plants are obligate seeders and won't re-sprout after they are burnt. They are killed by fire and depend on reproduction from seed, taking up to 5 years or more to reach maturity. *Callitris* pines take much longer to mature, and that means if we have fires at a frequency greater than 5 years, we start to lose those species. Fire-tolerant species such as speargrass then invade the sandstone heaths. It is vital that we gain an understanding of their fire ecology and develop methods to stop large fires coming into the sandstone, both from within and outside the Park.

6 Conclusion

Burning patterns have changed since Europeans arrived and there is a legacy of inappropriate fire regimes for the conservation of biodiversity. The Aboriginal traditional fire regimes were obviously appropriate because the biodiversity is there. The fire regime changes included more frequent fires later in the Dry season: larger, hotter, and more destructive. Our aim in adopting or simulating the Aboriginal burning patterns is to break the country up by lighting early Dry season fires and creating a mosaic of small patches with differing fire histories. In this way large destructive fires are avoided because the breaks are already in place when the inevitable late fires occur. While the Aboriginal custodians are well aware of this, and use their knowledge to manipulate the system with great skill, western scientific research results also indicate that these patterns are most beneficial for the maintenance of biodiversity,

In the sandstone, where the highest levels of biodiversity and endemism are, the most serious fire management problem is caused by vast destructive fires sweeping across the boundary from outside the Park. In the wetlands, which are extremely important both culturally and as habitat for wildfowl and other species, the major research and management hurdles revolve around understanding the traditional burning patterns and achieving the same results with vastly reduced numbers of people involved.

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Traditional Aboriginal use of fire in wetlands

V Cooper

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1 A description of traditional burning

In the mid-Dry season each year, people will start to burn from the open woodland and work down towards the wetland system. The way Aboriginal people burn is by following the weather – the season's climate tells them when it is the right time to burn. They usually tell when the last storms in the Wet season occur, which are called 'knock em down storms'. The storms bring the wind which knocks the spear grass, twisting and turning it, so the spear grass falls flat. When Aboriginal people see that, they get ready for the burning season. That's when the early burn usually starts, first burning the woodland country, what they call the high land.

People then start watching the storms. Once the storms have finished, they know the next thing to come is the cold weather season, and that will bring the moisture out and form dew on the grass. People will start burning the higher, open woodland country first. They start by doing a patch burn, or what we call a 'test burn'. What people would usually do is burn a little bit of the country to see how the grass would burn. If it burns a fair distance, then no worries, it's good, they will come back the next day and keep burning it. So people will start burning the higher ground and work their way towards the wetland system, because the wetland and the flood plain areas are the last to be burnt.

People usually burn the country in the mornings. The reason why they burn in the morning is because the dew causes the fire to burn slowly and die out. They sometimes burn in the evening, because they know that the fire will burn during the evening with a slow wind behind it and die out during the night because of the dew.

Something people say is not to burn when there are big winds, because if you do, the place will be damaged. The traditional knowledge is that once you are burning a country you have to burn behind the wind, so the wind will push the fire forward. Those are the sort of things that traditional people learnt from their ancestors.

You have to look at which way the wind is blowing. We have different patterns of wind – slower wind, fast wind and light wind.

Fast wind carries the fire really fast and everything gets burnt. Slow wind will cause the fire to burn slowly. People start to gradually burn in late afternoon, morning and sometimes at night; they burn when it is much cooler. Then once you get down towards the floodplains, that's where you start looking at your food resources in that area, because if you burn too early on the floodplain, the freshwater long-neck turtle would get burnt. Turtles don't bury

[*] Adapted from transcript, July 1997

themselves very deep during that early period in the Wet season. You have to wait until late in the Dry season when the water table has started going down and the turtle bury themselves deeper. If you burn too early you will burn the freshwater turtle. The only way of finding that out, in the traditional way, is to go and look for the turtle yourself to find out if it is ready to burn. If you find some turtles still shallow, you know it is not the right time to burn. The freshwater turtle is the most important thing that people check. Once the water table goes down the turtle buries itself deeper, and then they can burn the country.

The other thing that the old traditional people say is that burning the floodplain is good because you burn most of the grass on the floodplain, and the next coming year it will make more grass for the magpie geese to lay their eggs. It cleans the old area. They usually burn around the jungle forest area, but they usually burn that early to protect the food, the yam and all that sort of stuff. If you burn late, the fire goes inside the jungle and damages all the food sources there, it is all gone.

So I think I'll leave it at that, and if anybody has any questions, I am happy to answer them.

2 Questions

Question: Could you give the reasons why traditional burning is done by Aboriginal people?

Why do we burn the country? The country tells us when to burn. If we don't burn the country, the country is not going to look after us; that's the old saying that Aboriginal people always have in their mind. So the reasons why we burn the country are:

- For hunting reasons
- To clear the vegetation for people to walk and hunt
- People feel good burning the country to make everything come alive. The animals come back; the wallabies, kangaroos, white cockatoos and black cockatoos come back and feed on the spear grass. The white and the black cockatoos come and feed on the burnt spear grass seeds; they are the main food source for the white and black cockatoo. Other little animals come and feed on things too. If you don't burn, going back to the food chains, all the other animals wear out that access to feed on things.

Question: Do you take the cultural sites, the sites of historical significance, into consideration when you burn?

Only the right people can go to burn there, those who know that country and know that site there. Some important places do get burnt.

Question: Is there any cultural significance in burning?

There are a lot of different burning techniques. You can burn along the country and if a fire is used for smoking animals, they are the sort of thing that continue on. With cultural reasons, people sort of follow on from their ancestors, back towards Dreamtime, so fire is the main important thing to Aboriginal people today and they see it as not only burning the country. Fire is used in other techniques like when a relative or a person passes away, you do a smoking ceremony. You smoke their vehicle, their house, the food and then you have to smoke the land. These sort of things are how it ties into a big picture.

Question: One of the biggest problems we find when we burn early in the year is that it's obviously easier to burn off all our planned areas, or even burn in sequence down the drainage lines, but the creek lines don't really dry out until later in the year and so they are *really vulnerable to impact from late season fires. Do people talk to you about how things happened in the old days with the problem of drainage lines burning later in the year?*

No. I mainly refer back to Arnhem Land, because that's where most of the people hunt and gather foods, more so than in Kakadu. They hunt where the river system or the creek system is, and every time people hunt there they usually burn. You get a broader knowledge of your country, where every little thing is. You know if there is a creek there, you have to burn all that to preserve it and that's what is happening in Arnhem Land. There are a lot of people that go hunting and they burn their clan boundary area, because if they don't burn it, people from the other clan boundary will burn their area and the fire will come over the boundary.

But there is not much activity here in Kakadu. It is much bigger, and harder trying to get to all the creek lines. Traditionally, people would burn for various reasons, like when hunting for yams and other food sources, or maybe when travelling to other places they would burn there.

Question: Does Arnhem Land get burnt much traditionally?

I don't know the areas east and west from here, but I think when there were more Aboriginal people living there, they used to burn traditionally. Most traditional burning occurs in Arnhem Land, that's where a lot of people burn traditionally.

Question: With the fire regime in Arnhem Land, satellite images we're getting suggest there are some large, intense fires coming through late in the Dry season. Is that simply because there's not many people there now, or is there some other reason for those late fires?

The spear grass is different in Arnhem Land than here. In Kakadu the spear grass is thicker, in Arnhem Land you have thinner spear grass; they are different. When you burn the thinner spear grass it doesn't do much damage to the country, that's what I have found in my work, looking at things in Arnhem Land and looking at things in Kakadu. The thinner spear grass in Arnhem Land doesn't burn as hot as in Kakadu, and you haven't got many people staying in Arnhem Land as people travel backwards and forwards. Also they haven't got the machinery and things we have got in Kakadu. Here we have got a helicopter doing the burning, people doing controlled burning, and all this sort of thing doesn't happen in Arnhem Land.

Question: Do they have the same ideas with burning early in the year as here in Kakadu?

No, it's different there. They have different seasons and they follow different things there than what it is here in Kakadu. In Kakadu Aboriginal people follow six seasons, but in Arnhem Land they only have four seasons. In those four seasons, different clan groupings and different areas have different knowledge of how to burn and at different times of the year, so some people will burn earlier, some people will wait and burn a bit later.

Question: So maybe they think because there is not so much fuel, it's not so important to burn early in the year and they don't have to worry so much?

Yes.

Question: Is Wet season burning a traditional method?

No it wasn't, not here in Kakadu. The work I am doing is looking at that. Some traditional people say the Wet season burn is not our traditional burn, and they are pretty upset about it. They say that if you want to follow the traditional burning you have to follow the way the season indicates to you.

Question: Although Wet season burning is not traditional, some Parks staff want to encourage Wet season burning to break up the big areas of spear grass (Sorghum intrans), because it has only one year's worth of seed and if you burn the spear grass before it sets *seed then it doesn't come back for the next few years. You are saying the black and white cockatoo in particular come onto the spear grass, so do you think that it's a good thing to promote Wet season burning?*

In my experience, if all speargrass went, when the Dry season comes and we go to hunt the animals, they are not going to be there because there is not any regrowth. However, Wet season burning is good in a way. It does act as a fire break in some areas I have seen, and then if we get a late fire go through that area, the burn would stop where the Wet season burn was done. So the Wet season burn does act as a good fire break for when you get late fires coming through.

It goes back to the traditional side of things, people get upset about it because it makes their hunting pattern much different.

Question: With monsoon forest, the problem seems to be that, over a number of years, the fuel inside the monsoon forest keeps on building up and you end up with early fires going through. One way or another the fire gets in there and seeps through all the litter layers. Is that something that just happens occasionally and you can't do much about?

That is something that does happen occasionally, but going back, it doesn't happen much in Kakadu. However, people in Arnhem Land usually go and hunt in the monsoon forest area. They usually burn there earlier while they are there hunting, digging for yams, because they know that there is not much wind in that area and the fire will burn really close – creeps in. So I have seen a lot of people do that in Arnhem Land, but it isn't done much around this area.

Question: Probably a good example is the monsoon forest behind the buildings at South Alligator Ranger Station. Fire had been kept out of there for a number of years, but when it did get in there it got into the litter layers and just kept going and going. Everyday we tried to put it out but it flared up again. I'm wondering, as far as long term management of monsoon forest goes, perhaps you have to protect the forest as much as you can and accept that once every 10 years or so, fire is going to get in there?

At this stage they are starting to look at most of the facts around the monsoon forest and they are working out a strategy of how to preserve it, to stop late fires getting into there. You have to burn around early and do a firebreak earlier. It is a bit hard because in Kakadu you have got so many rainforests, people are not going to go to every different place, but there is a concern about it and at several meetings people have raised that concern, so they are looking at a way to improve it.

Question: What about paperbark swamps? Do you see them as being like monsoon forests that shouldn't be burnt? Are paperbark swamps an area that gets burnt traditionally?

There is a good story about paperbark. If you burn the paperbark tree earlier in the year it doesn't get damaged. Because the tree holds water inside, it's one of our main trees; we know we can find water inside a paperbark tree. But if you burn late, the water in the paperbark tree will be drained out and it will kill it. That's why most of the people burn that area early because they know that it is water you can survive on late in the Dry season if you are travelling. For paperbarks, an early burn is OK, but a late burn is not. I remember one area in Kakadu that had a late burn, and a really big paperbark tree and a lot of other big trees got killed.

Question: Since the buffalo have been taken off the floodplains, the vegetation on the floodplain has changed and so has the fire regime. Also there is para grass on the floodplain now. What are your comments on that?

The removal of the buffalo has caused a fair bit of change. I remember when I was here in 1979, most of the floodplain area didn't used to get burnt because of the numbers of buffalo eating down the grass. Now that the buffalo have gone there is more fuel there and you really have to concentrate on how to control fire on the floodplains because it will burn hotter than it used to before. That's the sort of thing that we noticed in Kakadu; when there is more fuel on the floodplain it burns much hotter for the animals, so you have to get in virtually when the water starts going down and burn slowly.

<u>Question</u>: So it actually takes more fire management now to avoid those hot fires?

Yes, management of burning has increased.

<u>Question</u>: What do Aboriginal people think about the removal of the buffalo? Do people want them back?

Well, a lot of people are saying that they wouldn't mind the buffalo to come back, but then you get other people looking at what damage was done and how the floodplains are totally different now. Those people would prefer that the buffalo come back but in a controlled number, for a controlled measurement of impact.

<u>Question</u>: Do you know or can anyone else remember before the buffalo were even here, what the fires were like around then and if the Para grass in particular burnt hotter than any other grasses?

No, you would have to talk to some of the older people who used to shoot buffalo. They might have more experience on that.

<u>Question</u>: Is the problem with the floodplain burns being hotter now actually that it messes up collecting turtles and stuff? Is that the real problem?

I remember once, a couple of years back, there was a big burn at Boggy Plain. There was a big burn on the floodplain edge and a couple of days later we went out there to have a look. You could see that there were thousands and thousands of turtles that got cooked, because the grass was too thick and people didn't manage it properly to get a good controlled burn on it.

But we found what usually happens with burning on the floodplain is that the fire travels underneath the grass like in a little tunnel, it doesn't travel on top. You can stand there and spray with your slip-on fire-fighting unit and you think the fire is out, but it is still burning underneath.

<u>Question</u>: You mentioned clearing the country for turtles and geese. What other food resources are you burning the floodplains for?

Referring to the floodplain area? Well, people say they burn there for the risk of snakes, that's one of the main things. People burn when they are travelling from one place to the other, making a much clearer access for walking. The reasons why people burn the floodplains are for turtle hunting, and making the grass much better for the magpie geese and crocodiles to lay their eggs the next year.

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