Fire on the *Gapalg* (Floodplain): Contemporary Aboriginal and Other Burning Patterns in Kakadu National Park, Northern Australia

Sue J. Roberts
Department of Geography, School of Oriental and African Studies, University of London, Thornhaugh Street, London W1CH OXG, England.

ABSTRACT

Floodplain burning has become a critical management issue in Kakadu National Park. Since the eradication of the feral Asian water buffalo (*Bubalis bubalis*) from the Park, fuel loads, which had previously been suppressed by grazing and trampling, have increased substantially. This has resulted in changes to the fire ecology of the wetlands. There is, however, a dearth of documented information on the contemporary fire regimes of floodplain communities, especially on Aboriginal peoples' use of fire. This study examines a range of different fire patterns and their effects on *Melaleuca* spp. and open grass/sedgeland communities. In addition, Aboriginal peoples' knowledge and use of fire is documented. Preliminary findings indicate that the "fuelbreaks" created by early season burning by Park staff are not sufficient to prevent high intensity conflagrations later in the dry season. A number of extensive, high intensity fires were recorded during the late dry season of 1992. Most of these fires were accidental, although a few were lit by the Aboriginal informants in order to reduce fuel loads and "clean up" the country. It is suggested that such fires will become a more common phenomenon in the future given the recent changes to the floodplain communities.

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INTRODUCTION

Floodplain communities constitute a significant proportion of the 20,000 km² of Kakadu National Park which is internationally recognized by UNESCO World Heritage status listing. The wetlands, which are also identified under the Ramsar Convention of Wetlands of International Importance, provide ideal an habitat for millions of migratory and resident waterbirds and attract many tourists and visitors to the Park each year. In addition, the floodplains are highly valued by the Aboriginal residents of Kakadu as an abundant source of traditional foods.

Until quite recently (late 1980s), the wetlands of Kakadu also provided suitable conditions for the Asian water buffalo (*Bubalis bubalis*). The buffalo was introduced to northern Australia in the 1820s (Ridpath 1991), and a hide industry was established by the late 1800s, as numbers increased. In 1981 it was estimated that the total buffalo population exceeded 280,000 (Graham et al. 1982), although actual animal densities varied throughout the northern coastal regions. The environmental impacts of the water buffalo have been well documented (Braithwaite et al. 1984; Fogarty 1982; Russell-Smith 1985; and Stocker 1971a; 1971b). Stocker found that both grazing and trampling by the animals accelerated soil erosion, altered drainage channels, and led to saltwater intrusion, which had a deleterious effect on Cyperaceae and *Melaleuca* spp. communities. It was also noted by Fogarty (1982) that sites which had been disturbed by buffalo were particularly susceptible to invasion by exotic plants, most notably *Mimosa pigra* and *Hyptis suaveolens.*

In the early 1980s, the traditional Aboriginal owners of Kakadu expressed concern over the amount of environmental degradation caused by the buffalo and the resulting impact on bird life and traditional food sources. Since the 1980s the water buffalo have been gradually removed from Kakadu National Park under the Brucellosis and Tuberculosis Eradication Campaign (BTEC). The absence of such a large herbivore has led to an exponential increase in plant biomass. Prior to the BTEC, the floodplains were mostly denuded of vegetation; today they are covered in dense swards of graminoid and cyperaceaous vegetation. The increase in plant biomass now represents available fuel for floodplain fires.

Although there were occasional fires on the floodplains when the buffalo were present in high numbers, they were mostly small and infrequent (Neidjie pers.

Table 1. Fire management Objectives of Kakadu National Park Plan of Management (A.N.P.W.S. 1991).

The main objectives in relation to fire management are to:

- protect life and property within and adjacent to the Park;
- maintain, as far as practicable, traditional *bining* (Aboriginal) burning regimes within the Park;
- maintain biodiversity;
- promote research into the fire sensitivity of environments and species;
- provide for the identification and protection of sensitive environments and species;
- maintain community education and interpretation programs covering the role of fire in Kakadu;
- minimize the spread of fire from the Park to adjoining land;
- minimize the spread of fire into the Park from adjoining land; and
- monitor the effectiveness of Park fire management programs.

comm., 1993). This has, however, never been quantified. It is likely that wetland fires would have been a feature of the pre-European landscape (Hallam 1985). Aborigines have been using fire extensively throughout the landscape since their arrival to the Australian continent c. 38,000 year b.p. How much the human use of fire modified the environment has been widely debated (Clark 1983; Hallam 1985; Horton 1982; Jones 1969). Evidence from pollen core studies and charcoal dating suggests that there does appear to have been an increase in the use of fire since the arrival of the first humans to Australia that coincides with an expansion of sclerophyllous vegetation and a contraction of fire sensitive communities. However such change may also be climatically induced (Kershaw 1985). Nonetheless, it is evident from the archaeological and palynological sources that the relationship between Aboriginal people and fire has been a lengthy one.

During an overland expedition through the Alligator Rivers region, Leichardt (1847) noted that the Aboriginal people were "numerous". Keen (1981) estimated that the Aboriginal population of the region has been reduced to about 3% of its total population at the time of first contact with European settlers. It is likely therefore that the wetlands of Kakadu once supported a much greater number of Aboriginal people than they do today. It is also quite probable that fire would have been employed as a tool in order to hunt and to acquire traditional foods. Although early accounts are little more than the scant observations of explorers, they do provide some evidence of floodplain burning:

"The natives were very numerous and employing themselves either in fishing or burning the grass on the plains or digging for roots" (Leichardt 1847).

"The natives seemed to have burned the grass systematically along every watercourse and round every waterhole, in order to have them surrounded with young grass as soon as the rain sets in. . . . The natives, however frequently burn the high and stiff grass, particularly along shady creeks with the intention of driving the concealed game out of it." (Leichardt 1847).

Since these observations there has been a long period during which fires have been largely suppressed from the floodplains due to grazing and trampling of fuels by the buffalo. However, since the removal of buffalo from Kakadu, the floodplain commmunities are once again being fired by both Park staff and Aboriginal people. Floodplain burning has again become a major management issue within the Park. In recent years there have been a number of extensive, high intensity conflagrations which have resulted in high tree mortality, particularly among mature *Melaleuca* spp. populations.

The Board of Management, which comprises mostly the traditional Aboriginal owners of Kakadu, have set out a number of criteria for fire management policies in the Kakadu National Park Plan of Management (Australian National Parks and Wildlife Service 1991). One such objective is to "maintain as far as practicable traditional *bining* (Aboriginal) burning regimes within the Park". Park staff use fire extensively as a management tool to fulfil the objectives set out in the Plan of Management (Table 1). In addition, although the Aboriginal population is now much smaller than it once was, many Aboriginal people still use fire on hunting expeditions and as they travel through the country. In a study of the Gunei people in north central Arnhemland, Haynes (1985) provides an informative account of traditional burning practices within mostly Eucalyptus savanna woodland and forest. Yet there is little documented information on Aboriginal floodplain burning practices. In addition, there have been no studies of the fire ecology of the wetlands of northern Australia. Given the substantial changes that have taken place in the floodplain communities in recent years, it is relevant to examine what is the most appropriate use of fire and how it can be used as a management tool to maintain the grass/sedgelands and paperbark communities of Kakadu. A study was undertaken in Kakadu during 1992 and 1993 and this paper outlines the research project and its preliminary findings. The principal aims of the research were to document contemporary wetland fire patterns and to examine their effects on the *Melaleuca* spp. and floodplain communities of Kakadu National Park. In addition, the study examines Aboriginal peoples' knowledge of fire use in wetlands.

METHODS

Site Description

The study area lies within the coastal-riverine floodplain communities of Kakadu National Park, northern

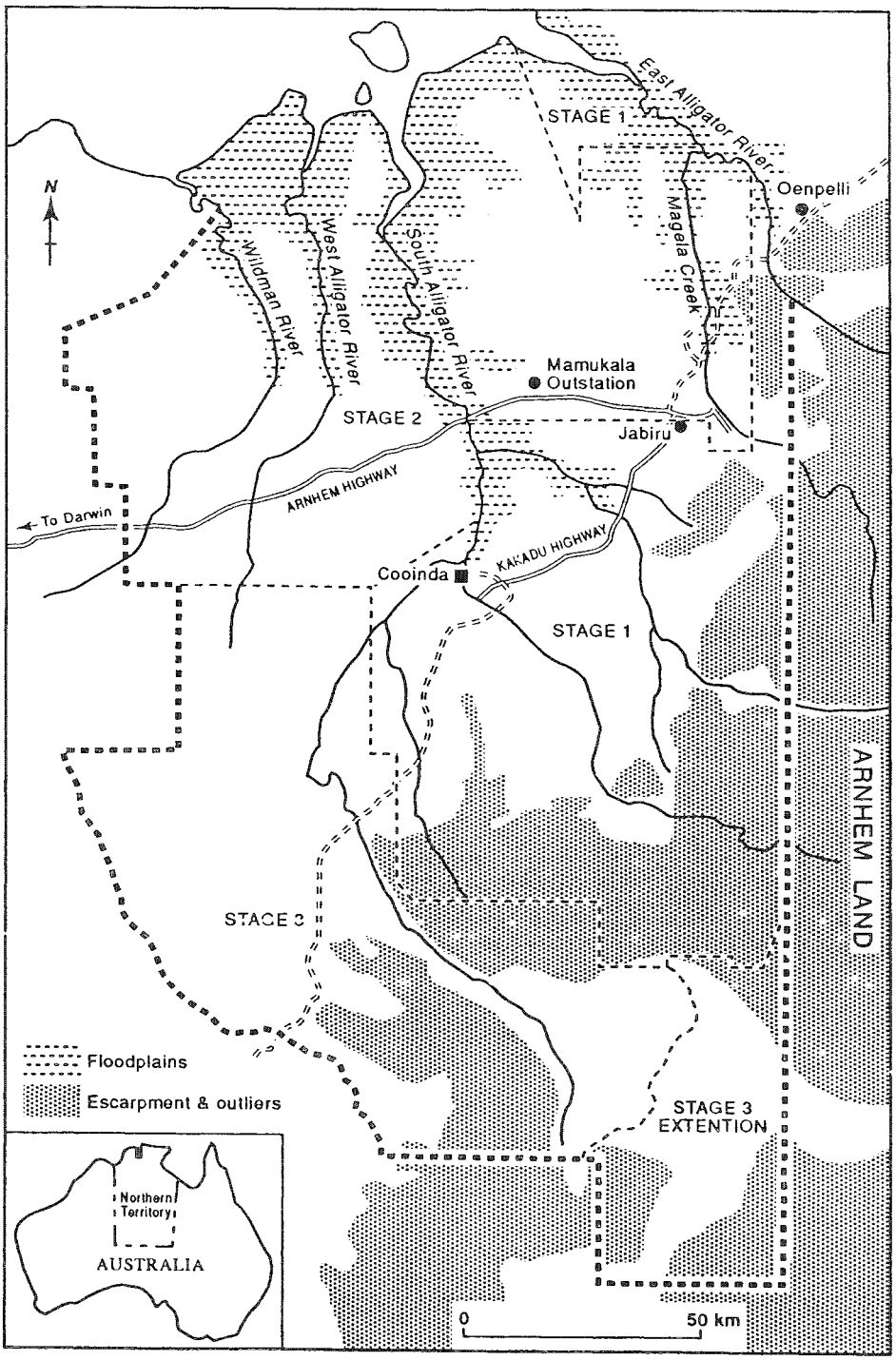

Fig. 1. Location of Kakadu National Park.

Australia, which lies approximately 200 km east of the city of Darwin (Figure 1).

The climate is monsoonal with the majority of rainfall occurring during the months of December through April (Table 2). Average daily maximum temperatures are above 30°C throughout the year. There are two major seasons: the dry season or winter (May to November) and the wet season or summer (December to April). However, the Gagadju people of Kakadu observe six distinct seasons (Alderson et al. 1980), these are based on both climatic changes and bio-indicators and differs somewhat from the Gregorian calendar (Table 2). The early part of the wet season is characterized by thunderstorms, and lightning strikes are a common ignition source for fire during this time. Cyclones can also occur during the summer months.

The wetlands of Kakadu comprise seasonally and permanently inundated floodplains, swamps, and bil-

Table 2. Climatic data for Kakadu National Park.

	Aboriginal seasons (*Gundjeidmi* language)												
	Gudjewg		Banggereng		Yegge	Wurrgeng		Gurrung		Gunumeleng		Gudjewg	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean rainfall (mm)	341	332	318	65	11	1	3	4	9	27	158	211	1437
Mean humidity (%)	81	85	81	68	61	57	57	58	59	63	69	75	68
Mean maximum temperature (°C)	33.5	33.1	33.1	34.4	33.4	31.3	31.5	33.6	35.7	37.5	36.5	34.9	34

Sources: Bureau of Meteorology, Darwin (1991); Alderson *et al* (1980).

labongs. The predominant plant species of the open floodplains are: *Cyperus* spp., *Oryza* spp., *Eleocharis* spp., and *Pseudoraphis spinescens*. Paperbark trees such as *Melaleuca cajeputi* and *M. viridiflora* occupy the seasonally inundated swamps and ecotonal forests and woodlands, while *M. leucadendra* generally colonises the wetter areas.

Measuring Fire Patterns

The current range of floodplain fire regimes (i.e., fires ignited by Aboriginal people and Park staff, lightning strikes, and wildfires) was documented over a 15-month period. The following data were recorded:

1. Fire intensity (kW m^{-1}) was calculated according to Byram's formula (Byram 1959) I=Hwr, which was derived from the following: (H) Calorific heat value of fuel—This was taken as a constant value for graminoid fuels (15,500 kJ/kg^{-1}) and woody fuels (20,000 kJ/kg^{-1}); (w) Fuel load—1 m^2 samples of vegetation were harvested in the path of fire. Samples were then weighed (kg m^2) and oven dried for 24 hours at 80°C in order to calculate the percentage of fuel moisture content (% oven dry weight); and (r) Rate of spread—A series of aluminium discs and 2 meter standards were placed at intervals along the fire front. The rate at which the fire moved was then timed (m s^{-1}).
2. Maximum temperature duration—A non-contact infra-red pyrometer was used to record the duration of maximum temperatures. Manual readings were taken every five seconds at either ground level or at heights of 0.5 or 1 meters. The pyrometer can be linked to a data-logger but given the difficulty of predicting the occurrence of fires, especially those lit by Aboriginal people and lightning strikes, it was more convenient to take manual readings.
3. Fire-weather—Relative humidity (%), ambient air temperature (°C), wind speed (m s^{-1}) and direction were recorded at each fire. The date of last rainfall was also noted. In addition the timing, extent, and type of fire was noted.
4. Post-fire effects—tree mortality and recruitment was monitored at a number of sites where fire behaviour was recorded. Eight transects were established and 100 *Melaleuca* spp. trees/saplings were tagged along each transect. Three of the transects were controls (i.e., no fires) in order to establish whether fire intensity determined tree mortality. Tree height and DBH were also recorded. The tags were relocated during the following dry season (10–12 months post-fire), and survivorship, mortality, and recruitment were noted.

Ethnological Data

The principal informants of this study were an Aboriginal couple who still spend much of their time on hunting excursions in the wetlands of Kakadu. Traditional Aboriginal owners and other resident Aboriginal people were also consulted in order to corroborate information. The use of fire by these Aboriginal people was observed during hunting excursions or when they were travelling through the country. Whenever possible, specific fire behavior was measured; however, as matches were often tossed from trucks as they drove along, it was not always possible to record all the fires lit. In addition to these observations and measurements of Aboriginal peoples' use of fire, extensive interviews and conversations were undertaken with all the informants on how they burn the floodplains.

FLOODPLAIN BURNING IN KAKADU

A total of 27 fires were measured during the period of study. An additional 20 fires were documented but data are incomplete. While findings at this stage are still preliminary the following section outlines the contemporary wetland burning patterns of Kakadu:

Prescribed Burning by Park Staff

Wetland burning begins early in the dry season, as soon as the graminoid and cyperaceous fuels will sustain fire (April/May). Park rangers progressively burn the floodplain margins using wind resistant matches thrown from vehicles, driptorches, and incendiary devices dropped from helicopters. These fires are lit primarily to reduce fuel loads and prevent the penetration of late

dry season fires into the fire sensitive communities (i.e., monsoon forests) and *Melaleuca* communities which border the open grass/sedgelands. Intensive protective burns are also carried out by the Rangers early in the dry season around monsoon forests, campsites, buildings, and along roadsides. Of the fires which were lit by Park staff and were measured, most had a low fire intensity and were managed effectively by the Park staff. Backburns were often applied initially, to control the extent and intensity of a secondary forward burn. However, although findings are preliminary, fire intensity and extent appear to be dependent upon fuel load and fire history (i.e., time since last fire) rather than time of year. For example, one early season fire lit in open grass/sedgeland which had not been burned for several years had a much higher intensity of 1649 kW m^{-1} (fuel load, 5.6 tons/ha) than one lit in a similar area which was fired annually (i.e., fire intensity: 66 kW m^{-1} fuel load, 2.8 tons/ha). Control of the former fire would have been lost had it not been for the presence of a river, and a drainage channel which limited the extent of the fire. During the period of study, the majority of prescribed fires lit by Park staff had been completed by early September. Most of the fires observed from this period onwards were lit by Aboriginal people, or were lightning strikes, or wildfires (i.e., accidentally lit).

Biningwulgang—"Blackfella Bin Burning"

Fires are lit by Aboriginal people for a number of reasons (Haynes 1985; Haynes 1991; Jones 1969; Lewis 1985; Lewis 1989a). The findings of this study were in agreement with the latter: floodplain and paperbark communities were fired to improve access, clear the country of snakes, promote new grass shoots to attract game, or to "clean up the country" (*gabbulemabun*).

As soon as the floodplain sedges and grasses will sustain fire, they are progressively burned by the Aboriginal people. The Aboriginal informants of this study tossed matches from their trucks as they drove to and from hunting sites. Thus, communities in and adjacent to favorite hunting grounds would be burned regularly. In fact, many areas were fired two or three times a year in order to promote new grass shoots, which attract grazing macropods. The Aboriginal women often lit fires along billabongs and watercourses as they searched for the northern snake-necked turtle (*Chelodina rugosa*), a favored traditional food.

The informants explained how the floodplains are "patch" burned progressively throughout the dry season: "burn im (the floodplain) little bit, little bit" (pers. comm. B. Ilkirr, 1992). However, once *Gurrung* begins (late August-October, "hot weather time") patch-burn size is likely to increase considerably and "he'll (the fire) go right through—big fire no good" (pers. comm. B. Neidjie, 1993). Some of the informants explained that fires at this time of the year could ignite the floodplain soils. Furthermore, they stated that such fires, which they called *Gunakurlul,* could lead to high mortality among the northern snake-necked turtle, (*Chelodina rugosa*) populations. However, some burning was carried out during the late dry season as some of the informants deemed it necessary to "clean up the country". They stated that there was too much thick grass and that it needed burning (*galarrwren*). Furthermore, most of the informants held the perception that there was now "too much grass" and this was due to the removal of the water buffalo from the Park during the 1980s.

Fires lit in the Cyperaceaeous/graminoid communities, similar to those lit by Park staff, were mostly low intensity "patch" burns (i.e., fire intensity <200 kW m^{-1}, fuel load <2 tons/ha). However, some early dry season floodplain fires reached fire intensities of >1500 kW m^{-1} (fuel loads >5 tons/ha); again this is variable and appears to be a function of fuel load accumulation rather than time of year.

The paperbark (*Melaleuca* spp.) communities were also fired throughout the dry season by the informants during hunting excursions. The fires occuring between May and July tended to be patchy, low intensity fires. In contrast, the conflagrations recorded during *Gurrung* had high fire intensities and many lasted for more than three weeks. For example, a mature paperbark forest was burned by one of the Aboriginal informants during October. The measured fire intensity of this conflagration was $>7{,}000$ kW m^{-1} (mean fuel load: 4.8 tons/ha). During this fire the *Melaleuca* spp. trees acted as ladder fuels and flames reached the tree canopy. In addition, a number of trees were hollow and the interior of the trees were ignited. The Aboriginal informants refer to this (fire in hollow trees or torching) as *Gunak Ruey.* On another occasion an Aboriginal woman fired a *Melaleuca* spp. forest in September while looking for northern snake-necked turtles (*Chelodina rugosa*). According to the informant, the fire was lit to clear the thick grass within the paperbark forest, to enable her to reach the billabong edge to search for turtles. This conflagration reached a fire intensity of 1728 kW m^{-1} (mean fuel load: 5.4 tons/ha). Interestingly, several other Aboriginal women who were also present that day expressed their concern about this fire and stated that it was too late in the year to burn paperbark forest (D.Lucas, pers. comm., 1992). There does appear to be a number of different opinions amongst the informants about late season burning of the floodplain communities, particularly *Melaleuca* spp communities for example:

"You can burn im, he's (*Melaleuca* spp.) alright he's got family inside" (meaning paperbarks will produce epi-

cormic shoots following firing) (B. Ilkirr, pers comm., 1992).

"when he's (paperbark tree) hollow him burn inside, him fall down but young one (tree) he never die, leaf come new (vegetative reproduction)". (Informant, 1992)

"paperbarks this time (July) you can burn im cos you burn little bit slow—no matter he go up top (of the tree) he's alright (but) August, September, November no good too hot" (B. Neidjie, pers. comm., 1993).

Wildfires and Lightning-Ignitions

Despite the extensive early burning by the Park Rangers and Aboriginal people there were a number of wildfires during the late dry season of 1992. One conflagration was caused by a re-ignition: the fire spread into a paperbark swamp which had not been burnt for many years (according to interpretation of satellite imagery). However, the fuel load was relatively low (5.1 tons/ha) for paperbark forest, a humic soil sustained the fire, and developed into a crown fire which is a rare phenomenon in northern Australia (Dunlop and Webb 1991). In addition, fire whirls about eight meters in height were observed and a fire intensity of $>10{,}800$ kW m^{-1} was recorded, although it became too dangerous to take measurements due to the high incidence of fire spotting. Post-fire effects were noted 10 months after the fire: 100% crown death had resulted (n=100); 78% of the tagged trees were dead or dormant; and 22% had new epicormic buds present. Furthermore, there had been high seedling recruitment following this fire.

In addition, during *Gunumeleng* (November/December) a number of lightning-ignited fires were observed. Some of these lasted several days, while others were extinguished by ensuing rainstorms. It was discovered that lightning had struck at almost the identical place on the same day, 3rd December, in 1990 and 1992, and in both instances had started large floodplain fires.

DuRieu (1993) estimated from interpretation of remote sensing imagery that 45.9% of Kakadu's wetlands were burned in 1992. However, it is suggested that this figure could be somewhat higher as a number of extensive floodplain/paperbark fires did occur from September to December but were not included as satellite imagery is incomplete for this period due to high level of cloud cover during the pre-monsoonal storms.

FIRE MANAGEMENT IMPLICATIONS

At the time of this study the Park's fire management policy was to carry out prescribed burning during the early and mid-dry season; staff ceased burning the wetlands beyond September. However, a number of Aboriginal informants continued to burn *Melaleuca* spp. and other floodplain communities after the Rangers had stopped burning, as they felt that such areas had too much grass or leaf litter and needed firing. This was often irrespective of the ensuing ecological consequences. This issue has been addressed by Lewis (1989b), who observed conflagrations set by Aboriginal people in the eucalypt savannas of Kakadu. He suggested that "in the eyes of Aboriginal people the problem is not late season fires, the problem is that there are insufficient early season fires." However with respect to the floodplain communities the issue is somewhat more complex than this. While conclusions at this stage, prior to data analysis, can only be tentative, it is suggested that given the recent changes in fuel loads and availability, due to the removal of buffalo, many seasonally inundated swamps will now sustain fire, but not until late in the dry season (i.e., October to December). Fires, particularly sub-surface burns, occurring at this time tend to be severe and can be deleterious, particularly to mature *Melaleuca* spp. communities. The "fuelbreaks" created by Park staff earlier in the dry season were not sufficient to prevent the occurrence and spread of fires later in the dry season.

It is suggested that, in future, the prescribed burning program by Park rangers may have to extend into the late dry season in order to break up fuel loads and help contain the spread of any accidental fires. Furthermore, it is advised that staff consult the Aboriginal people more closely, particularly during the late dry season on how much should be burned in order to "clean up" their country. Finally, a tremendous wealth of traditional Aboriginal knowledge still exists on fire behaviour in Kakadu; land managers, not only those in Kakadu but elsewhere in Australia, should consult traditional Aboriginal ecological knowledge while they still have the opportunity.

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LITERATURE CITED

Alderson, M. T. Gangali, and C. Haynes. 1980. Seasonal calendar for the Kakadu region in *Gundjeidmi* (*Maiili*) language. Kakadu National Park Plan of Management. Australian Government Publishing Service, Canberra.

Australian National Parks and Wildlife Service. 1991. Kakadu National Park Plan of Management. Australian Government Publishing Service, Canberra.

Braithwaite, R. W., Dudzinski, M. L., Ridpath, M. G., and Parker, B. S. 1984. The impact of water buffalo on the monsoon forest ecosystem in Kakadu National Park. Australian Journal of Ecology 9:309–322.

Byram, G. M. 1959. Combustion of forest fuels. Pages 61–89 *in* K. P. Davies, ed. Forest fire: Control and use. McGraw Hill, New York.

Clark, R. L. 1983. Pollen and charcoal evidence for the effects of Aboriginal burning on the vegetation of Australia. Archaeology in Oceania 18:32–37.

Dunlop, C. R. and L. J. Webb. 1991. Flora and vegetation. Pages 41–59 *in* C. D. Haynes, M. G. Ridpath and M. A. J. Williams, eds. Monsoonal Australia: Landscape ecology and man in the northern lowlands. A. A. Balkema, Rotterdam.

DuRieu, R. 1993. Kakadu firescar monitoring. Unpublished consultancy report to Australian National Parks and Wildlife Service, Darwin.

Fogarty, P. 1982. A preliminary survey of environmental damage associated with activitiy of feral buffalo. Unpublished report to the Conservation Commission of the Northern Territory, Darwin, Australia.

Graham, A. R., R. Begg, P. Graham, and S. Raskin. 1982. An

aerial survey of Buffalo in the Northern Territory. Unpublished report to the Conservation Commission of the Northern Territory, Darwin, Australia.

Hallam, S.J. 1985. The history of Aboriginal firing. Pages 7–20 *in* J. Ford, ed. Fire ecology and management in Western Australia. Environmental Studies Group Bulletin 14. Western Australia Institute of Technology, Bentley, Western Australia.

Haynes, C. D. 1985. The pattern and ecology of Munwag: Traditional Aboriginal fire regimes in north central Arnhemland. Pages 203–214 *in* M. G. Ridpath and L. K. Corbett, eds. Ecology of the Wet-Dry Tropics. Proceedings of the Ecological Society of Australia 13.

Haynes, C. D. 1991. Use and impact of fire. Pages 61–71 *in* C. D. Haynes, M. G. Ridpath, and M. A. J. Williams, eds. Monsoonal Australia: Landscape ecology and man in the northern lowlands. A. A. Balkema, Rotterdam.

Horton, D. R. 1982. The burning question: Aborigines, fire and Australian ecosystems. Mankind 13:237–251.

Jones, R. 1969. Fire-stick farming. Australian Natural History 16:224–228.

Keen, I. 1981. The Alligator Rivers Aborigines: retrospect and prospect. Pages 171–186 *in* R. Jones, ed. Northern Australia: options and implications. Research School Pacific Studies, Australian National University, Canberra.

Kershaw, A.P. 1985. An extended late Quarternary vegetation record from north-eastern Queensland and its implication for the seasonal tropics of Australia. Proceedings of the Ecological Society of Australia 13: 179–189.

Leichardt, L. 1847. Journal of an overland expedition in Australia. T. W. Boone, London.

Lewis, H. T. 1985. Burning the Top End: Kangaroos and Cattle. Pages 21–31 *in* J. Ford, ed. Fire ecology and management in Western Australian ecosystems. Environmental Studies Group Bulletin 14. Western Australian Institute of Technology, Bentley, Western Australia.

Lewis, H. T. 1989a. Non-agricultural management of plants and animals: alternative burning strategies in northern Australia. Pages 54–73 *in* Hudon, R. J., Drew, K. R., and Baskin, L. M. eds. Wildlife production systems: economic utilisation of wild ungulates. Cambridge University Press, Cambridge.

Lewis, H. T. 1989b. Ecological and technological knowledge of fire: Aborigines versus park rangers in northern Australia. American Anthropologist 91:940–961.

Ridpath, M.G. 1991. Feral mammals and their environment. Pages 169–191 *in* C. D. Haynes, M. G. Ridpath and M. A. J. Williams, eds. Monsoonal Australia: Landscape ecology and man in the northern lowlands. A. A. Balkema, Rotterdam.

Russell-Smith, J. 1985. A record of change: studies of Holocene vegetation history in the South Alligator River region, Northern Territory. Proceedings of the Ecological Society of Australia 13:191–202.

Stocker, G. C. 1971a. The effects of water buffaloes on paperbark forest in the Northern Territory. Australian Forest Research 5:29–34.

Stocker, G. C. 1971b. Water buffaloes and conservation in the Northern Territory. Wildlife in Australia 8:10–12.