"An assessment of the impact of a managed buffalo population on woody vegetation in a tropical wetland area."

This thesis is submitted by Jan Riley (Batchelor of Education, Graduate Diploma in Geographic Information Systems), in partial fulfilment of the requirements of the degree of Master of Tropical Environmental Management in the School of Science and Primary Industries, Faculty of Education Health and Science, Charles Darwin University. It is submitted in June 2005.
Declaration

I declare that this thesis is my own work and has not been submitted in any form for any other degree or diploma at any university or other institute of tertiary education. Information derived from the published and unpublished work of others has been acknowledged in the text and list of references.

Signed: [Signature]

Date: 17 June 2005
Abstract

Landscape change and change in vegetation density in particular, is a topic of enormous interest in Northern Australia and around the world. Varied factors can cause change including the density of feral animals and changed grazing patterns. Kakadu National Park is a World Heritage area situated in Australia’s Northern Territory. Between 1825 and 1843 Bubulus bubalis, the Asian water buffalo, was introduced to the Northern Territory. Peak numbers of buffalo occurred in the Park in the early to mid 1970’s. They were almost total eliminated by the early 1990’s. A buffalo farm was formed in Kakadu National Park in 1989 and is still operating today. The establishment of this farm provides a unique scientific opportunity to explore both the effects of a low density buffalo population on the floodplain landscape and the ability of a buffalo degenerated landscape to regenerate with a managed buffalo population present.

A GIS was used to analyse the study site. A point grid was created to sample a 15 meter area from every 50 metres over the study site. Attributes of forest, scrub, plain and channel were allocated to each point in the floodplain grid over the colour photograph coverage years of 1984, 1991, and 2004 and also the black and white coverage’s of 1964 and 1975. Spatial subsets reflecting different farm management history and the different study areas outside the farm were used to assist in the identification of different processes or drivers of change.

There has been significant increase in woody vegetation over the entire study site in the 40 years from 1964 to 2004. This increase appears to reflect the density of buffalo population at any point in time and can certainly be linked to the removal of feral buffalo from the area. The paddock areas have increased woody vegetation at a substantially lower rate than the subsets external to the buffalo farm. It would appear that there is sufficient evidence that buffalo have had some effect on the regeneration of the floodplain. This effect is limited to a retardation of the regeneration and is not degrading the floodplain. It would then appear that with effective management it is possible to graze buffalo on floodplain areas without incurring degradation to the land.
Acknowledgements

This study would not have been possible without the unwavering support of my husband Trevor.

I acknowledge the funding and in kind support of Parks Australia North, in particular Michael Misso, Fiona Peek and Anne Ferguson. A special thanks to Caroline Lehman and Jo Dibble of the Charles Darwin University School for Tropical Environment and Management. I also acknowledge the assistance of eriss in particular Peter Bayliss and James Boyden. This study would not have been possible without the most generous sharing of information from the manager of the Buffalo Farm Dave Lindner. I also thank the Northern Territory State Reference Library for allowing me access to their photographic archives. Finally I thank my supervisors Dr Guy Boggs and Jeremy Freeman for their time and constructive assistance.
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<td>ANPWS</td>
<td>Australian national Parks and wildlife Service</td>
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<td>NDVI</td>
<td>Normalised Difference Vegetation Indices</td>
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<td>PAN</td>
<td>Parks Australia Northern Territory University</td>
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<td>RGB</td>
<td>Red, Green, Blue spectral bands</td>
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Introduction

Landscape change and changes in vegetation density in particular, is a topic of enormous interest in Northern Australia and around the world. It is also a contentious issue with the observed changing patterns of vegetation density and distribution being assessed by various parties as positive, negative or even neutral. There are many interrelated factors that contribute to this changing density.

The change can be either thickening or thinning of vegetation density and can result from a single factor such as deliberate land clearance or it may be the result of multiple factors. Varied factors can cause change for example, changed fire regimes, climate change including altered rainfall and rising temperatures together with elevated CO$_2$ levels fuelling an increase in photosynthesis, the establishment of introduced species of vegetation, density of feral animals and changed grazing patterns often brought about by the establishment of pastoral properties.

Kakadu National Park is a World Heritage area situated in Australia’s Northern Territory. Between 1825 and 1843 Bubulus bubalis, the Asian water buffalo, was introduced into the Northern Territory. The story of buffalo in Kakadu National Park is consistent with the overall history of buffalo in the Top End with peak numbers of buffalo occurring in the Park in the early to mid 1970’s and almost total eliminated by the early 1990’s. A buffalo farm was formed in Kakadu National Park in 1989 and is still operating today. The establishment of this farm provides a unique scientific opportunity to explore both the effects of a low density buffalo population on the floodplain landscape and the ability of a buffalo degenerated landscape to regenerate with a managed buffalo population present.
Aims and Objectives

Aim:

To measure the impact of a managed buffalo population on woody vegetation in a tropical wetland area.

Objectives:

1. Classify land cover inside and adjacent to the buffalo farm from a series of aerial photographs;
2. Establish trends of change in woody vegetation change inside and outside the buffalo farm before the buffalo farm was established;
3. Compare changes in woody vegetation both inside and outside the farm since the establishment of the farm;
4. Compare differences in change of woody vegetation under different farm management strategies;
5. Assess factors, other than management which may cause variations in woody vegetation over time.
Background

Vegetation change

Observed vegetation change

General thickening of woody vegetation and replacement of grasses and shrubs by woody vegetation has been reported in Northern Australia (Jacklyn P., 2000). Some studies report merely thickening of existing vegetation (Bowman D.M.J.S. et al., 2001) whilst others report woody vegetation where none previously existed (Sharp B.R. and Bowman D.M.J.S., 2004b). The Sharp study reported the increase to be specifically attributable to a proliferation of *Melaleuca* sp.. An internal preliminary report for the Supervising Scientist (Riley J. and Lowry J., 2002) determined that whilst there was certainly significant increase in *Melaleuca* in some areas of the Magela floodplain in the Northern Territory this was offset by the reduction in numbers in other areas of the same floodplain. The factors driving these changes are currently still speculative.

Causes of change

Aside from land clearance one of the most obvious single causes of landscape change in the Top End of the Northern Territory has been the pressure on the land from introduced grazers. This was primarily brought about by the establishment of pastoral properties which introduced large numbers of cattle and by the vast numbers of feral buffalo that inhabited the region. There have been multiple effects from grazing. To maximise production pastoralists have introduced exotic pasture species of vegetation such as the South American *Brachiaria mutica* (Para grass) and African grasses *Andropogon gayanus* (Gamba grass) and *Pennisetum polystachyon* (Mission grass) which have contributed to change in the vegetative landscape (Finlayson C.M. et al., 1997). The introduced species of grasses burn much hotter than native grasses and have the potential to initiate a grass-fire cycle in the savanna regions of Northern Australia (Rossiter N.A. et al., 2003). Dense grazing by feral animals changes the composition of native
are not standardised and have different reflectance values. Satellite images are generally not rectified with the same precision as aerial photographs partly because of the large pixel size. It has been found that using ground control points for rectification of satellite images can result in more accurate rectification than using topographic map derived points. However significant landscape change can be detected erroneously where the change may simply reflect different methods of determining the coordinates of ground control points (Smith D.P. and Atkinson S.F., 2001).

It is important to note that aerial photography has been available in some areas from the 1940’s whereas satellite imagery has only been available from the late 1970’s. When analysing landscape change, the 25 years of satellite imagery is very limiting.

**Aerial Photography**

In a study by Harvey (Harvey K.R. and Hill G.J.E., 2001) the accuracy of Landsat TM and Spot coverage was compared to the accuracy obtained from large scale aerial photographs and it was determined that aerial photography gave a more accurate result. Aerial photography has the significant advantage of a far greater resolution than satellite imagery. By virtue of this fact aerial photography is often used for the purpose of ground truthing satellite imagery (Fensham R. et al., 2002) and is regarded as an accurate representation of reality.

There are also disadvantages with aerial photographs. For example the variation in colour within each photograph from the centre to the outside can be quite marked. Any change in the angle of the sun on to the subject area between frames can also cause marked change of colour and a variation in what is depicted or visible on the ground. There is limited availability of infra red photography and consequently most aerial photographs have a very limited RGB spectral profile. The four aerial photographs below (Figure 1) were taken in 1991 and are of the same point. They are either adjacent photographs or are from adjacent runs.
1991: Same area, adjacent photographs

Figure 1: Examples of variation in aerial photograph colour

Analysis of aerial photographs is often labour intensive and reliant on visual discrimination using shape and texture rather than the spectral auto discrimination which is available with satellite imagery. The big advantage of aerial photography is the there is far greater availability of historical aerial photography with a fine scale.

Ground Survey

The most accurate and detailed method of observation of landscape change is to repeatedly ground survey large components of an area over many years. This involves the accurate identification and recording of all species found, together with the recording of the density of species from the ground to the canopies. It also involves the recording of the composition of the terrain including soil composition, slope etc. This methodology is then
repeated over a period of years and analysed to ascertain change. It is an expensive method as it is labour, time and resource intensive. Another important limitation associated with ground survey is that sampling can not be carried out retrospectively.

There are several accepted methods of ground survey and the choice of method is dependant on many factors. The aim for all methods is, in a systematic way, to identify species and structure on the ground that is relevant to the study. There are two main methods of ground survey, transects and point or quadrat. These can be carried out either randomly or systematically.

**Buffalo**

**Origin**

Between 1825 and 1843 *Bubulus bubalis*, the Asian water buffalo, was introduced to the Top End of Australia’s Northern Territory. A few buffalo were initially introduced to the Cobourg Peninsular of the Top End of Australia in 1829. Another three shipments totalling less than 100 were landed at Port Essington in 1838 ((McNight T., 1976), (Skeat A.J. et al., 1996)). These animals were introduced mainly to provide a source of meat for the remote settlements but they also had a role as beasts of burden ((Department of Environment and Heritage, 2004a), (Bowman D.M.J.S., 2003)). The settlements to which the animals were introduced eventually failed and the buffalo were abandoned. The habitat in which the buffalo were left was nearly ideal for them and they extended their range to occupy the Top End wetlands north of Latitude 16° S. Buffalo numbers in the area increased rapidly and an estimated 20,000 animals inhabited the Cobourg Peninsula area by the mid 1870’s (McNight T., 1976). The estimated peak in buffalo numbers across the Top End was in the 1970’s (Letts G.A., 1979), (Lindner D., 2005). In 1985, after this high point, an aerial survey of 223,672km² of the Top End estimated that there were some 340,000 buffalo in the area. This represents an average density of one per 1.53km². Some
areas in fact had a density in excess of 10 km$^2$ (Bayliss P. and Yeomans K M., 1989a).

**Economy**

Whilst environmentalists have decried the buffalo for the environmental damage they caused while in large numbers, the buffalo has also had economic value to the Top End. Buffalo initially became an economic resource when a buffalo hide industry developed. The hunting of buffalo for hides became an attractant for European settlement in the area (Skeat A.J. et al., 1996). Animals were slaughtered and the hides removed in the field with the majority of the meat going to waste. Between 1886 and 1911 over 100,000 hides were exported (Letts G.A., 1979). In the 1950’s the hide industry faltered due to a slump in the world market (Bowman D.M.J.S., 2003), (McNight T., 1976) and buffalo numbers in the Kakadu and Arnhem Land area escalated.

Beginning in the mid 1950’s a market developed in buffalo meat for human consumption. A live buffalo industry developed with animals exported to South East Asia and Hong Kong. By 1960 there was also a pet food market for buffalo meat. Three buffalo abattoirs were established in the Northern Territory, one of these, Mudginberry, was located in what is now Kakadu National Park. In the 1973 -1974 year, 23,000 buffalo worth $1.7million were utilised for human consumption, and a further 3,000 were utilised in the pet food industry (Letts G.A., 1979). Another commercial aspect of the buffalo industry is hunting and hunting safaris. Even today buffalo are regarded as prized game with buffalo horns a sought after commodity. It is estimated that some 700,000 buffalo have been harvested from the Top End since the 1980’s (Department of Environment and Heritage, 2004a). The Department of Primary Production surveyed property owners in the Top End wetland areas in the early 1980’s and two-thirds of those surveyed claimed that feral buffalo were a major source of income (Robinson C.J. and Whitehead P., 2003).
Traditional Owner Attachment

Over the period of time that buffalo have been a part of the Top End, the Traditional Owners of the land have grown to accept them as a cultural and economic benefit and also as part of the landscape. They also came to use the animals as a source of meat. A major advantage of buffalo meat to the Traditional Owners is that there are fewer cultural prohibitions on the hunting and consumption of buffalo in contrast to native wildlife such as kangaroo and emus (Altman J.C., 1982)), (Bowman D.M.J.S., 2003), (Bowman D. M. J. S., 2002). It has been suggested that some Aboriginal communities regard the removal of buffalo from the land to be a negative as the re-establishment of vegetation has seen the emergence of invasive species of vegetation which have made access to hunting and fishing areas difficult (Robinson C.J. and Whitehead P., 2004). In moderate numbers buffalo are regarded by Traditional Owners as having a place in the landscape not just for the meat that they provide but in a historical context. Many Traditional Owners and their families have been involved in the buffalo industry up to the end of BTEC and so buffalo have a significant part in their history (Bayliss P., 2003; Petty A. et al., 2005).

Impact

Buffalo have a limited home range and form an attachment to their home area. An adult male buffalo weighs around 1,200kg and eats up to 30kg of dry food a day (Department of Environment and Heritage, 2004a). The animals habitually visit the same drinking, wallowing, dunging areas and rest areas. By 1979 it had been observed that buffalo had been responsible for considerable degradation of the landscape. The changes brought about by buffalo included not just degradation of the land and soil itself but marked adverse effects on vegetation, natural waters, drainage, faunal habitat and fire regime (Letts G.A., 1979; Taylor J.A. and Friend G.R., 1984).

There have been many studies into the impact of Buffalo on the landscape and all agree that at high densities, buffalo have an extremely negative impact (Letts G.A., 1979; Robinson C.J. and Whitehead P., 2003; Skeat A.J. et al., 1996; Taylor J.A. and Friend G.R., 1984).
Buffalo are large heavy animals and many of the land systems found in the floodplain are shallow cracking clays that are easily disturbed and damaged. Prolonged use of tracks into waterways can initiate erosion and the breaking down of levees.

Buffalo have, by their preference for wetland, created swim channels, disturbed the sedimentary layer at the base of wetland, broken levees that retain salt water and fresh water, silted and contaminated water supplies, created wallows, initiated erosion and generally damaged wetland areas with their trampling.

By selectively eating specific vegetation buffalo cause change to biodiversity. The pressure of grazing on native grasses can be intense depending on the density of animals inhabiting the area. This pressure can also alter the vegetative composition of the area grazed which then has a flow on effect to the usability of the area for wildlife that require species specific habitats. Buffalo also use trees as rubbing posts and this can cause the demise of some of the taller vegetation.

While there are many negatives from the grazing of buffalo there are two positives. The first is that it has been determined that heavy grazing, by removing the grass vegetative layer, facilitates the growth of juvenile woody plants and increases their chance of survival as competition for nutrients is lessened (Sharp B.R. and Bowman D.M.J.S., 2004b; Werner P A. et al., 2005). The second positive is that the presence of grazing animals has been shown to reduce the loss of larger trees by reducing the amount of fuel on the ground near woody plants. Reduction in fuel levels results in less intense burning near the basal area leading to increased longevity for older woody vegetation. (Sharp B.R. and Bowman D.M.J.S., 2004a; Werner P A. et al., 2005).

It has been shown that the South Alligator floodplain has a substantial ability to repair itself from buffalo damage to some degree. There has been
considerable reversal of damage to the floodplain area channels and vegetation since the removal of buffalo (Petty A. et al., 2005), (Freeman J., 2005).

**Brucellosis and Tuberculosis Eradication Campaign (BTEC)**

As early as the 1970’s it was accepted that the density of buffalo in the Top End was a problem and The Letts Inquiry was commissioned in 1979 to make recommendations for the control of feral animals in the Northern Territory. Letts reported that in the Woolwonga reserve, now part of Kakadu National Park, between 1971 and 1977, 25,000 buffalo had been removed leaving a residual population of 4,000. He noted:

“Already a marked general improvement in the regrowth of grass and the understorey of shrubs and young trees can be seen.”

Cattle in the Northern Territory, as with cattle throughout Australia, were known to contract and carry Brucellosis and Tuberculosis. A nationwide programme, BTEC was initiated with the aim of eliminating these two diseases from livestock or reducing the occurrence of them to a sufficient minimum to enable Australian meat to be classified disease free and be acceptable in the world market. Although buffalo do not contract Brucellosis they do contract Tuberculosis and therefore all buffalo over the age of 6 months became part of BTEC, requiring mass culling of the population.

**Kakadu National Park**

**General description**

Kakadu National Park is an area of around 20,000km² situated in the Alligator Rivers region of Australia’s Northern Territory. It consists of four main land forms, the Arnhem Land Plateau and associated escarpment, Coastal riparian plains, the southern hills and basins and the Koolpinyah surface. The Arnhem Land Plateau is the catchment for the vast amounts of water that flow through the Alligator Rivers system and other waterways in the area.
Kakadu National Park is a World Heritage site listed for cultural and biodiversity reasons. In excess of 1600 plant species have been recorded in the park. Kakadu National Park is one of only 23 sites worldwide recognized for both natural and cultural factors.

Kakadu National Park is also a Ramsar listed wetland area of international importance. The Ramsar convention on wetlands was signed in Ramsar, Iran, in 1971 and is an intergovernmental treaty for the conservation and wise use of wetlands. There are currently 144 contracting parties to Ramsar and some 1420 wetland sites worldwide. (RAMSAR, 2005)


A major component of the Kakadu landscape is the South Alligator River floodplain. This floodplain does not have a continuous channel flowing to the ocean. Water from the Arnhem Plateau and the other catchment areas flows via the South Alligator River, and other creeks and waterways into a series of billabongs and channels in the south of the floodplain area. The South Alligator River then reforms in the northern area of this floodplain. This northern section of the South Alligator River then flows to the ocean and is influenced by tidal activity.

The South Alligator floodplain has undergone many changes since the 19th Century. These include the introduction and expansion of buffalo numbers together with changes to land forms and floral and faunal composition brought about by the presence of high numbers of buffalo. There have also been changes in fire regimes, the introduction of invasive plant species and the creation of networks of roads and bridges and increased impact from tourism.
On the South Alligator floodplain tidal variance can be up to 8 metres. High tides reverse the fresh water flow and allow saline water up the river channel for some distance inland creating a large tidal interface region. The force of water up the channels on a high tide can be considerable and there is a naturally occurring system of channels and levees that protect the freshwater floodplains from tidal influences. These levees and channels are easily damaged and during the period of high buffalo numbers much damage was done to them (Finlayson C.M. et al., 1997; Letts G.A., 1979; Petty A. et al., 2005; Werner P A. et al., 2005).

The breaking down of levees has two major impacts on the floodplains. It allows the influx of saline water into the freshwater floodplains. It also provides an escape for the freshwater contained on the plains. The consequence is that the level of water withheld on the floodplain drops. Each of these processes has considerable impact on the floodplain itself together with the flora and fauna of the plain.

Over 50% of the land in Kakadu National Park is Aboriginal land and it is known from evidence in the Park that Aboriginal people have occupied the area for in excess of 50,000 years. The Kakadu Board of Management has been created by virtue of s376 of the Environment Protection and Biodiversity Conservation Act.

This Board was established for the Park in 1989 and consists of 15 members with 10 Aboriginal members representing the Traditional Owners of the land. The Commonwealth Director of National Parks together with the Board is responsible for preparing plans of management for the Park (Department of Environment and Heritage, 2004c).

The Board of Management, Parks Australian North (PAN) and the Traditional Owners all have responsibility for the maintenance and integrity of Kakadu National Park and initiate and support projects that contribute to the understanding of the dynamics within the landscape of Kakadu. Resources
have been used to establish an extensive historical aerial photographic coverage of the Park.

**Buffalo History in KNP**

The story of buffalo in Kakadu National Park is consistent with the overall history of buffalo in the Top End. The 1960s and 1970’s saw very high numbers of feral buffalo with the peak of numbers in the Alligator Rivers region of the park occurring in the early to mid 1970’s. Due to a very cold dry season possibly with frost and consequent lack of grass, there was a large die out of buffalo from starvation in the Kakadu region in 1972 (Lindner D., 2005). Between 1950 and 1975 when buffalo numbers expanded to their maximum density in the area, it has been determined that channel formation on the floodplain far exceeded channel disappearance. By 1991 a marked reduction in the number of channels in the area was detected, a fact that is consistent with the marked decline in buffalo numbers in the area during the BTEC project (Petty A. et al., 2005).

Floodplain vegetation is affected by factors such as water depth and the period of time that each area is inundated (Finlayson C.M. et al., 1988). Buffalo, by damaging levees, and creating swim channels affect both of these elements and consequently may be considered to have caused or contributed to changed vegetation pattern in the area.

At the time of the BTEC, prevalence of Tuberculosis in buffalo in the floodplains of the Park was very high (3-15%) with some areas having a prevalence of (30-50%). (Robinson C.J. and Whitehead P., 2003). The BTEC culling commenced in the Park in 1979 and continued until 1997. The programme had many problems in the Park area including the extremely large and inhospitable nature of the area in which the buffalo lived. In the late 1980’s helicopter shoot outs of the animals to waste became the most cost effective method of eradication, although the efficiency of helicopter shoot out decreased as the density of the buffalo’s lessened and more time was spent searching out animals (Bayliss P. and Yeomans K M., 1989a).
Buffalo were all but removed from Kakadu National Park during this campaign. Between 1980 and 1989 approximately 80,000 buffalo were removed, an estimated 20,000 head remained. (Robinson C.J. and Whitehead P., 2003). The BTEC campaign continued officially until 1997. A residual population of less than 250 was estimated to be in the Park in 1996 (Department of Environment and Heritage, 2004a).

One negative aspect of the removal of buffalo was that Traditional Owners of the area lost a valued source of what had become a meat of choice. This loss of buffalo meat resulted in a decision by the Gagudju Association, an organisation of Traditional Owners of the area, to create a buffalo farm. The buffalo farm was established in Kakadu National Park in 1989 to provide a secure source of buffalo meat to its members in Kakadu.

The Buffalo Farm

An Environmental Impact Assessment was formulated in September 1989 to support a request from the Gagudju Association to the Director of The Australian National Parks and Wildlife Service (ANPWS) for approval of the creation of a farm. It was proposed to establish a herd of up to 2,000 head of buffalo.

The supply of meat to the Traditional Owners was to be, and indeed has been, a free service with the meat delivered to the consumers. Land owners can legally kill animals for their own consumption and as the Traditional Owners of the land are the consumers this arrangement is both practical and lawful. The buffalo farm is situated in Kakadu National Park on the eastern side of the South Alligator floodplain some 70 km south of the ocean and 200 km SE of Darwin. The farm is approximately 12,000 ha in area and is 13 x 17 km at its widest points. The area of land that is now the farm was chosen from an area of some 150 square kilometres in the Anbarrawarrku Billabong area (Goose Camp 2) north of Cooinda on the South Alligator River Floodplain and consists of 110 Km² of low nutrient savanna woodlands with lateritic soil and 6 km² of good tidal mud deposition, now freshwater ephemeral swamp, wetland.
The manager appointed to establish and run the farm was Mr. Dave Lindner who has lived on the farm and managed it from inception.

At the time of creation of the Buffalo Farm the then ANPWS, now PAN, was required to oversee the monitoring of the environmental effect of the project. It has continued to do so since 1989. The Gagudju Association has been responsible for financing the running of the farm. Part of the responsibility of the Kakadu National Park Board of Management is an obligation to understand the impact of the buffalo farm.
Summary

The presence of feral buffalo in the Top End has had an enormous impact on the land from the 1950’s until their removal between the late 1970’s and the 1990’s. While buffalo were responsible for much damage they became an icon of the Northern Territory and had economic benefit to many people. The buffalo farm in Kakadu National Park was established at the time feral buffalo were removed from the surrounding land providing a natural experiment.

Management history is available from the farm manager who established the farm in 1989. Kakadu National Park is a World Heritage area and is the subject of much research. There exists a comprehensive historical aerial photographic archive of the area.

All of these factors combine to provide a unique scientific opportunity to explore both the effects of a low density buffalo population on the floodplain landscape and the ability of a buffalo degenerated landscape to regenerate with a managed buffalo population present.
Method

This chapter focuses on the methodology used in the classification of the aerial photographs. It initially focuses on the situation and history of the study site and then focuses on the rationale behind the site selection. It then moves onward to the data preparation of the aerial photographs, the choice of sampling method and the process used for sampling of the study site.

Study Area

Kakadu National park is in the wet / dry tropics of the Northern Territory and is predominantly savanna and floodplain. The savanna is dominated by Eucalyptus species. The floodplain areas are dominated by native grass species and have a predominantly Melaleuca fringe with areas of Mangrove in the riverine areas. The Park receives, on average, 1500mm of rainfall per year.
The Alligator River Area has been divided into descriptive land systems by Galloway and these definitions will be adopted by this project (Galloway R. W., 1976).

Figure 4: Map of study site land units

Table 1: Land units

<table>
<thead>
<tr>
<th>Land Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copeman 1 Cm</td>
<td>Low estuarine plains, muds, clays, herbaceous swamp</td>
</tr>
<tr>
<td>Cyperus 1 Cp</td>
<td>Seasonally flooded, muds, poorly drained clays, sedgeland</td>
</tr>
<tr>
<td>Jay J</td>
<td>Poorly drained sands and clays, lateritic red earths and less well drained yellow earths, woodland.</td>
</tr>
<tr>
<td>Kay K</td>
<td>Lateritic red earths, alluvial flats and channels. Variable vegetation.</td>
</tr>
<tr>
<td>Knifehandle Kn</td>
<td>Fine textured alluvium, floors of shallow valleys, mixed scrub, grassland.</td>
</tr>
<tr>
<td>Kosher Kh</td>
<td>Adjacent to cyperus. Sandy slopes, shallow loams patchy grass land</td>
</tr>
</tbody>
</table>
Buffalo farm

History

The buffalo farm was established in 1989 at a site east of the South Alligator River, and north of Yellow Waters in Kakadu National Park.

At this time the floodplain area was predominantly covered by grasses such as *Hymenachne acutigluma* with *Eleocharis* spp and patches of *Pseudoraphis spinescens* and *Oryza meridionalis*. Various species of grasses/ground cover occur on the plain but are not sufficiently visible on the aerial photographs to be consistently identified and therefore are not able to be classified. The margin of the floodplain consisted of *Melaleuca* spp and *Barringtonia acutangula*. The buffalo stock was to be run on this floodplain pasture in the dry season and on woodland in the wet.

The groundwork was carried out at the buffalo farm site in 1988 with the farm first stocked in 1989. The farm was, and is, fenced externally to prevent the escape of buffalo and internally to assist movement and management of the animals.

The Gagudju Association obtained from Goodparla Station 500 weaner buffalo and 50 weaner cattle and these became the first stock on the farm. Weaners were specifically chosen as they did not carry Tuberculosis (Lindner D., 2005). There was a big loss of stock with 200 head failing to survive the early phase, 100 of these died during the initial pellet feeding phase. The remaining 300 head of weaners survived to form the nucleus herd. To compensate for the initial loss, in 1990, 50 adult head were supplied to the farm from the Mann River region in Arnhem Land, a tuberculosis free area.

Management and Expansion

The external dimensions of the farm have changed over time. The majority of the farm was established in 1989 and some internal fence-lines have changed in this area since establishment especially in the floodplain which was originally 7 paddocks and is now 4. In 1994 a paddock of some 23Km²
was established on the Eastern side of the farm. The final addition to the farm was in 1997 when the most southern paddock of some 27km$^2$ and one floodplain paddock were established. A total of 6km of fence, generally in the floodplain area, has been lost due to wet season inundation factors since 1998. Finance has not been available to repair these fence-lines. Corridors of 3 to 4 km in length were created between some paddocks to assist with the movement of buffalo but these have not been maintained and are now substantially overgrown. The boundary fence line is fully maintained. (Lindner D., 2005).

Since 1996 the funding has not been available from the Gagudju Association to maintain the farm and management has been conducted on a mostly voluntary basis by the farm manager. Parks Australia North does not have a specific fund allocated to the buffalo farm but it does provide in-kind support to help in the maintenance of the farm.

Generally buffalo prefer to live in a home range and do not seek to escape. If removed from their home range they would seek to return. When buffalo do escape the farm, PAN is notified and these animals are shot by the rangers. To date approximately 50 animals have absconded and been shot since 1989.

Whilst the buffalo population has been a domestic herd with animals able to be mustered and yarded easily, it has now reverted to a more wild status. If it were necessary to truck the animals now, portable yards would be needed to avoid fence destruction. While some of the older cows are able to be mustered they have generally lost calves in the harvest process and so are quite protective of their progeny and can consequently be quite dangerous to intruders in the paddock.

The farm has had three main phases to its development:

1) 1988 – 1994 Establishment. The maturation of stock and a breeding programme to increase numbers;
2) 1995 – 1997 Productive. Fully productive and supplying and delivering meat. Domesticated herd divided into breeding and slaughter herds in separate paddocks;

3) 1998 – 2005 Volunteer Status. Gagudju Association no longer funding the farm. Farm run on a voluntary basis by Manager assisted by PAN;

![Figure 5: Buffalo Farm Paddocks at 1992 and 2004](image)

Over time the numbers on buffalo on the farm have varied from the initial stocking of 500 weaners to a maximum of 1,000 head in 1999. The manager prefers to keep the numbers to around 400 head.

Stock numbers;
1989 - 500 Buffalo weaners, 50 steer.
1991 - 339 Buffalo and 50+ steer.
1993 - 514 Buffalo and 73 steer.
1994 - 650 Buffalo and 74 steer
1997 - 1000 head approx
2004 – 600 head approx and 17 steers
Currently the Buffalo Farm area is burned throughout the year to encourage new and more palatable growth of feed for the buffalo. This burning is carried out by the manager whenever possible beginning at the cessation of the heavy rains around the end of March each year. Until recently the manager has assumed responsibility for burning both in and around the farm and so the fire history inside and outside the farm is similar. Heavy burning is carried out around the area of the farm that houses the buildings. Burning is also specifically carried out to protect fence lines.

Burning of other areas of the Park is carried out by PAN and tends to incorporate burning on a wider scale in a shorter time frame.

**Site selection**

The buffalo farm and surrounding land can be divided into the two main topographic components being floodplain and savanna. The vegetative composition of these two areas is quite different and the texture and
The floodplain has broad areas of plain with scattered vegetation generally together with dense vegetation on the fringe. As this study focuses on the floodplain alone it was necessary to choose a methodology specifically suited specifically to the floodplain.

It was essential to accurately map the boundary of the buffalo farm to delineate between the inside and outside of the farm. It was also necessary to map the individual paddocks to allow comparison between different paddock subsets of the farm that had different management histories. A topographic map, a land system map and DEM coverage of the area together with management information from the farm manager were used to create an accurate map of the buffalo farm. (Figure 8)

The buffalo farm is situated in the intertidal zone where salt water intrusion or influence from the ocean fades. Areas of floodplain further north or south of the farm, apart from those directly adjacent to it, were excluded as they have different combinations of fresh and salt water. Selection of comparable areas of floodplain outside the farm was problematic as a large portion of the farm floodplain is almost bay like and covers an extensive area of approximately 8 km$^2$. The areas of floodplain adjacent to and outside the farm generally face directly onto the larger floodplain and do not have this enclosed aspect. It was decided to incorporate an area of floodplain on the western side of the South Alligator River some 5 km distant from the buffalo farm as this area was more directly comparable to the internal floodplain of the farm. Whilst this area is west of the farm it is within the breadth of latitude covered by the farm and is the nearest area of floodplain to the farm that has a comparable location and hydrology. It covers an area of approximately 7 km$^2$.

Areas of floodplain that abut the South Alligator River were excluded from the site selection as they have a different ecosystem from the floodplain within the farm. The vegetation in this area is generally a mangrove dominated riparian one and not comparable to the buffalo farm ecosystem.
Fire frequency data from 1980 to 2004 was consulted so that any areas that had been affected by fire far differently from the other floodplain areas could be removed from the study. Information from the farm manager relating to fire within and around the farm was also used for this purpose.

The land unit coverage of Kakadu National Park was used to determine what land units were in the study site.

The floodplain area studied focuses on the intertidal zone which is affected by periodic inundation and includes the Melaleuca forest floodplain fringe. There is little variation in the elevation on the floodplain. It was necessary to identify the floodplain and intertidal area and exclude both riverine areas and areas with higher elevation. With the use of a DEM several methods were tried to allow selection of sites with a similar elevation and slope both inside and outside the buffalo farm.

A DEM was displayed underneath a transparent coverage of the 2004 photograph mosaic of the area to effectively display the slope of the land. Tides can reach the 8 metre mark. The 8, 9 and 10 metre delineation points were considered as the high point for the floodplain and fringe. After visual analysis of the DEM under the mosaic it was decided that the 3 metre mark was an effective low point to limit the floodplain. Areas below this level were more affected by the South Alligator River and the vegetation changed to a riparian, mangrove dominated landscape. The 3 metre mark effectively removed the major stream areas which are not applicable to this study. The 10 metre / 3 metre and the 9 metre / 3 metre coverage intruded too far into the savanna areas. The 8 metre / 3 metre coverage did not effectively select all areas of floodplain either inside or outside the farm.
The final study site was a combination of the 3 metre mark as an approximate low point and the upper edge of the floodplain was visually discerned and digitised by hand. Figure 7: DEM under paddock map, shows the 2-3 metre mark in green. This effectively illustrates the low points of the study site.
The School for Environmental Research has created a flight line GIS database covering all photography over Kakadu National Park. These flight paths were reviewed to ascertain the correct photographs for the project which were then sourced from various agencies. The flight line GIS is not fully edited and complete and therefore still has errors resulting in incorrect photographs being sourced and scanned. Additional time was necessary to ascertain and source the correct photographs. It has been found that desktop scanners can have low geometric accuracy and that much of the information on film is lost in the scanning process (Fensham R. et al., 2002). Trial scans also showed the need to use a high quality scanner. A high quality scanner was not immediately available and this caused delay. The 2004 photographs were already in a digital format and so did not need to be scanned however the images did have a brownish wash over them and the colour range was limited. The brown wash was removed using adjust auto levels in Photoshop. The photographs showed far greater discernable
contrast once they were adjusted. A complete list of aerial photographs and
details relevant to the scanning of them can be found in appendix 1.

It was decided that it was appropriate to create photographic mosaics for
each year of coverage and to establish a method of sampling for this area.

Every second photograph was chosen to scan and rectify as this gave a 10% overlap between photographs to allow mosaics to be created. Where every consecutive photograph was available a consecutive coverage was scanned especially in the black and white coverage of 1964 and 1975 to aid analysis. Coverage from each of the years 1964, 1975, 1984, 1991 and 2004 were used. The photographs were used in the project as tiles rather than creating and using a true mosaic. The overlap between the various frames and runs can depict the same area differently for various reasons. Colour can vary between frames as the lens of the camera was at a different angle to the vegetation. The terrain can be depicted differently from different angles. Soil reflects differently at different angles to the sun and vegetation that is visible in one frame can be obscured in another. Shadow from varying crown sizes from woody vegetation can also have varying effects from frame to frame and between runs (Fensham R. et al., 2002). It was very useful to use the overlap area to compare vegetation from one frame to another with some frames depicting an area far more clearly than their neighbouring frame.
Rectification

It was necessary for the floodplain photographs to be rectified with low error to third order as it was important that the photographs from different years overlaid precisely. The 2004 images, being the most visually clear, were rectified to the digital 1:50,000 topographic sheets. This 2004 mosaic was then used as the base layer to rectify all other images. The other images were rectified on a photograph to photograph basis which was a much easier process as there is far more detail in photographs. The RMS for the 2004 images was generally under 10. Photo to photo was generally less than 10. One run in the 2004 coverage appears skewed which resulted in a higher RMS.

Data Processing

Automated interpretation of the aerial photography was considered but several intrinsic components of photographs make the use of automated
classification unreliable. This is mainly due to the limited spectral profile of aerial photographs which are generally restricted to RGB. The Kakadu Landscape change project currently underway at the Charles Darwin University School for Environmental Research had tried the use of e-Cognition™ on the South Alligator Floodplain. This software uses spectral and spatial information to classify the land. Unfortunately there was a large amount of manual editing necessary after the automated process. The manual editing process was so time intensive that the automated process was abandoned. Also it is not possible to use the same automated process on black and white and RGB photographs. The coverage from both 1964 and 1975 were in black and white.

In a study of change of Melaleuca densities in 2002, simple image classification of a photographic mosaic was tried with unreliable outcomes due to the variation in colour caused by different angles between the camera and objects within and between each photograph. The variation in colour within each photograph from the centre to the outside can be quite marked and the change in the angle of the sun on to the subject area between frames can also cause marked change between photographs. Although techniques were used to reconcile this variation the results were not sufficiently uniform to allow automated interpretation (Riley J. and Lowry J., 2002). Subjective assessments are required of the difference between scrub and forest. An automated process is not yet available process for this purpose.

**Floodplain Sampling**

Several methods of sampling the floodplain area were contemplated and tested with several adjustments and refinements.

1. The first method was random points. Several densities of random point were tried but it was determined that as the vegetation was so sparse the density of grid points needed to accurately sample the floodplain was too intense.
2. The second method was limited comparative sites. Choosing an estimated 8 areas of floodplain, four inside the farm and four outside the farm, and placing a point grid over these and classifying each point by land cover. It was decided that it would be preferable to sample the entire study site rather than components of it. This was considered achievable within the time available.

3. The third method tested was applying a point grid over the entire floodplain. Grid point dispersal at intervals of 10 metre, 100 metre and 50 metre were all tested. Creation of the 10 metre dispersal took the computer some 40 minutes to process and was obviously too unwieldy. The computer crashed twice in attempting the task. The 100 metre dispersal was too sparse with much detail missed. It was decided to adopt the 50 metre point grid for the project. An open reticule of 50 metres was considered but it was decided that as vegetation was so scattered in areas it would be more appropriate to use a sampling method that took in more area than just a point.

A point grid with a dispersal of 50 metres was created and the icon chosen to be placed at each interval was an empty or transparent circle. The photographs were then displayed at different scales under the grid to assess the scale necessary to accurately evaluate the vegetation. A 1:3000 scale of display for the photographs was adopted and the grid icon was adjusted in size and evaluated at this 1:3000 scale. It was decided that displayed at 1:3000 a circle of 20 pts displayed an effective 15 metre radius. This then meant that every 50 metres a sample of 15 metres was being taken. This combination was adopted for the project.

The point grid was then cut down in Arcmap™ to cover just the floodplain site areas selected from DEM and ancillary information as detailed earlier. This encompassed in excess of 16,000 grid sample points components each of which required an attribute to be allocated to them for each of the 5 years, a total of some 80,000 points. This was considered an acceptable number because of the level of detail that would be provided by the exercise and was also achievable in terms of visual classification.
Classification

One other study in the Kakadu Landscape change project looks at change on the South Alligator Floodplain (Petty A., 2003). This study looks exclusively at channel change. The classes adopted by that project were:

- Mangrove;
- Forest;
- Scrub;
- Plain;
- Channel.

It was decided to adopt the classes used in the South Alligator channel change project with some modification. The mangrove class was deleted. The floodplain sites included in this project did not extend to the mangrove areas there being no mangrove areas within the farm. Although forest and scrub are both woody vegetation and this project is specifically evaluating woody vegetation change, it was considered that a differentiation between the two may prove to be insightful in its own right.

The land cover classes adopted for this study were:

- Forest;
- Scrub;
- Plain;
- Channel.

In the South Alligator vegetation change study the classes were species based and did not focus on the floodplain fringe as did this current study. For the purpose of this study, and ease of classification, classification based upon the structure of the vegetation was applied. Therefore species identified as scrub could be the same species as forest but at different density and growth stage.

The parameters used to allocate attributes were:

- Scrub = low and sparse woody vegetation;
Forest = tall or dense or tall and dense woody vegetation;  
Channel = minor channels not major waterways;  
Plain = no woody vegetation.

Where a portion of a circle was plain with some woody vegetation present the vegetation took priority in the allocation of that attribute. Where a channel was present it took priority over all else.

**Allocation of attributes**

![Allocation of attributes](image)

Figure 10: Allocation of attributes

Attributes were allocated to each point in the floodplain grid over the colour photograph coverage years of 1984, 1991, and 2004 and also the black and white coverage's of 1964 and 1975. To minimise operator error, when all allocation of attributes was complete, each coverage was inspected closely at 1:10,000 to detect any error. Each coverage was then again inspected at 1:5000 to confirm correctness. During this control process it was found that there was some cross over between scrub and forest. This was corrected and made consistent throughout each coverage. Where burnt areas were encountered in the 1984 and 1991 coverage, deletion of those areas from the
floodplain site was considered. Evaluation of these areas and their neighbouring unburnt areas together with reference to other photographic coverage of made it possible in each case to effectively allocate attributes.

Figure 11: Data analysis process
General trends can be ascertained from a broad analysis but to identify the specific drivers of change or the different processes involved in change it is necessary to identify different patterns that appear at different scales. Spatial subsets or tiers will be used to assist in the identification of these different processes or drivers of change.
Figure 13: Map of tiers

Tier 1 is the entire study site and will be looked at to ascertain general trends of the study site seen as a whole.

Tier 2 is Tier 1 divided into two subsets of,

All areas that are outside the buffalo farm and
All areas that are inside the buffalo farm.

Tier 3 is the two subsets of tier 2, further subset.

Outside the buffalo farm, is divided into,

The west floodplain
The buffalo farm fringe

Inside the buffalo farm subset is divided chronologically into the area from which

Paddocks were formed pre 1992
Paddocks were formed post 1992.
Tier 4 consists of two components of tier 3 namely, Paddocks formed pre 1992 and paddocks formed post 1992 further subset into individual paddocks numbered from 1 to 8.

It has not been possible in this study to carry out ground truthing. The floodplain of the buffalo farm and the wider floodplain were either inundated or water affected at the time of this study making the ground truthing of these areas impossible. It has however been acknowledge that aerial photography can give a more accurate estimation of woody vegetation that ground survey (Sharp B.R. and Bowman D.M.J.S., 2004b).
Results

This chapter presents the results of this study. Analysis is broken into the 4 tiers illustrated in Figure 12; a map of these tiers follows at Figure 13. The graph, Figure 14, shows the general distribution of the four attribute classes and it is here to illustrate the proportions of land cover classes mapped. It illustrates the necessity to absorb the two minor classes of channel and scrub for effective analysis. The results are generally presented as the two class analysis of, no woody vegetation and woody vegetation. A general breakdown of attribute points into these two classes can be seen in Figure 15.

![Figure 14: Sample point percentage for four class breakdown](image-url)
This study aims to identify whether a controlled population of known numbers of buffalo is one of the drivers of changes within the buffalo farm. It attempts initially to ascertain patterns of change throughout the entire study site and to identify the various drivers of these changes. These patterns of change are then to be compared to pattern of change within the buffalo farm.

The varying fire regimes, elevation, geomorphology and buffalo history of all subsets will be considered as general drivers of change. Management factors for the buffalo farm will also be considered.

As the study seeks to identify the effect of buffalo on the increase of woody vegetation the results will be expressed in terms of gain or loss in woody vegetation. The term woody vegetation represents the combined forest and scrub classes. If a trend of note is apparent in one of the four individual, more specific classes, of forest, scrub, plain or channel there will be comment on this separately.

The change in individual attributes is, unless stated otherwise, always shown as a percentage change from 1964 values. If there were 100 sample points in 1964, 120 in 1975 and 135 in 1984, 1975 would be represented as 20%.
1984 as 35%. Any reference to percentage change in channel sample points would be misleading as there are few channel sample points therefore any reference to channel will be to the actual number of sample points.

Although the allocation of attributes has been checked and rechecked, where discretion is involved in the allocation of an attribute there is always the possibility of a small variation although this is unlikely. (See Figure 10) The combination of channel with plain and scrub with forest results in 2 classes that require no discretion as they are absolute. If woody vegetation is present in any sample point it took the attribute of scrub or forest. The result of this combination is a presence/absence of all vegetation except grasses/ground cover.

**Tier 1:**

**Whole study site**

![Tier 1: 1964 to 2004](image)

**Figure 16: Tier 1 graph**

When the entire floodplain study area is evaluated, (Figure 8), as a single entity for increase in woody vegetation, the graph, (Figure 16), shows no change in woody vegetation between 1964 and 1975, followed by a minor
increase between 1975 and 1984. From 1984 onward this increase becomes more marked.

**Tier 2:**

**Inside Vs Outside buffalo farm**

![Tier 2 graph](image)

Figure 17: Tier 2 graph

Woody vegetation inside and outside the buffalo farm has had quite different trends from 1964 to 2004. The subset, outside the farm, decreased in woody vegetation almost 10% or -0.8% per annum from 1964 to 1975 where the subset of inside the buffalo farm increased in woody vegetation by 10% between the same years. Both subsets had by 1991 increased in woody vegetation from 1964, the outside subset by 19%, the inside subset by an almost identical 18%.

The outside subset has increased its rate of increase in woody vegetation from 1.78% pa between 1975 and 1984 to 3.75% pa from 1991 to 2004. This is twice the rate of increase prior to 1991. Inside the buffalo farm had an
average increase of 0.98%pa prior to 1991 and exactly the same rate 0.98%pa from 1991 to 2004.

Figure 18: Tier 2 scrub graph

The scrub sub-class was quite volatile between 1964 and 1991. There has been no correlation between scrub sample point numbers inside and outside the farm.
Figure 19: Tier 2 channel graph

It can be seen from Figure 19 above that while the channel sample point numbers were small there was a marked peak in numbers in 1975 and 1984 in both areas with a decrease in channel points beginning by 1984 and a significant fall from then until 2004 in both areas.

**Tier 3:**

Tier 3 consists of four component subsets. Tier 3 reflects the two quite separate study sites environments outside the buffalo farm namely the west floodplain and the area termed the buffalo farm fringe. It also consists of the floodplain paddocks divided into the two separate management areas of the late dry season use paddocks and the early dry season use paddocks. The late dry season use paddocks were all created prior to 1992 and are termed, pre 1992 paddocks, in tier 3. The early dry season use paddocks were created at various times post 1992, and are termed, post 1992 paddocks, in tier 3.
Figure 20: Tier 3 graph

The two subsets of tier 3 that are outside the buffalo farm changed differently from the two paddock subsets and also differently from each other.

The pre and post 1992 paddock areas changed at a very similar rate from 1964 to 1984 recording a gentle but continual rise in woody vegetation numbers. From 1984 onward the pre 1992 paddock area increased woody vegetation at a consistently greater rate than the post 1992 paddock area.

When the 2 outside subsets, the buffalo farm fringe and the west floodplain are compared it is seen that they changed quite differently from each other. While they both decreased in woody vegetation from 1964 to 1975 the west floodplain area decreased woody vegetation numbers by almost 20% or 1.69%pa between 1964 and 1975. It did not begin to increase again until between 1984 and 1991 when it recorded an average increase of 4.27%pa whereas the buffalo farm fringe began to increase woody vegetation in 1975. It should be noted here that although the west floodplain increased the least of all subsets to 1984, from 1984 to 1991 the overall percentage increase in woody vegetation from 1964 to 2004, in this area, was far greater than any other area.
When fire frequency is analysed for each area it can be seen that the west floodplain has been burned infrequently from 1980 to 1991 as has a large proportion of the buffalo farm fringe. The paddock areas have varied fire frequency rates.

**Tier 4**

**Trends in individual paddocks**
This tier comprises the pre 1992 and the post 1992 paddock areas divided into individual paddocks.

Paddocks 1 to 5 were formed before 1992 and are used in the late dry season. The farm manager's home is situated in paddock 5 and the grazing history of this paddock is not known. It is possible that this paddock is not grazed. Paddocks 6, 7 and 8 were formed post 1992. Paddocks 7 and 8 are used in the early dry season. Paddock 6 is a special case. It was formed in 1997, one of the last paddocks formed, and it has since been disused as a paddock. The farm manager terms this paddock derelict and unusable. While it is of interest to follow the vegetation change in this paddock it has not had the grazing history of the other paddocks and so can not accurately be compared to them.

**Figure 21: Tier 4 graph**
The percentage increases in woody vegetation throughout all the paddocks from 1964 to 2004 have varied considerably but the trends of change between most paddocks have been similar.

All paddocks except paddocks 1 and 8 increased in woody vegetation between 1964 and 1975. The increase varied from around 11% in paddocks 5, 6 and 7 to around 30% in paddocks 2 and 3.

The general trend from 1975 to 1991 was for each paddock to remain within about 5% of its 1975 level with the exception of paddocks 3 and 5 which recorded different results. All paddocks have continued to increase in woody vegetation.

Paddock 3 decreased woody vegetation from 1975 to 1984 and then showed a marked increase to 1991.

Paddock 5, was the paddock with the greatest change. It followed the same trends as the majority of paddocks until 1984 with an increase in woody vegetation averaging 0.8% per annum. From 1984 until 1991 the recorded result for this paddock has been markedly different from all other paddocks with woody vegetation sample points increasing dramatically by an average 6.86%pa from 1984 to 1991. Between 1991 and 2004 this high rate of increase continued and woody vegetation increased at a rate three times greater than the next greatest increase which was in paddock 4 adjacent to it.

Paddocks 3 and 4 showed the next greatest increase in woody vegetation. These two paddocks have had consistently high increase in woody vegetation from 1975.

Paddocks 1, 2, 6, 7 and 8, whilst increasing at different rates, have shown the same or a similar trend since 1984.
Paddock 8, while increasing at a sustained rate, has recorded the lowest increase of all paddocks. It has increased in woody vegetation by 5.5% since 1964.

The woody vegetation increase between 1964 and 2004 for the paddocks used in the late dry season, which are also the paddocks formed before 1992, have increased in order:

<table>
<thead>
<tr>
<th>Paddock</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paddock 1</td>
<td>19%</td>
</tr>
<tr>
<td>Paddock 2</td>
<td>32%</td>
</tr>
<tr>
<td>Paddock 3</td>
<td>59%</td>
</tr>
<tr>
<td>Paddock 4</td>
<td>67%</td>
</tr>
<tr>
<td>Paddock 5</td>
<td>164%</td>
</tr>
</tbody>
</table>

The paddocks used in the early dry season paddocks 7 and 8 have increased woody vegetation quite differently from each other:

<table>
<thead>
<tr>
<th>Paddock</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paddock 7</td>
<td>26%</td>
</tr>
<tr>
<td>Paddock 8</td>
<td>06%</td>
</tr>
</tbody>
</table>

It should be noted that paddocks 3, 4, 5 and 7 did not ever have a channel sample point in them. Paddock 8 had 1 in 1975, paddock 1 had 4 in 1975, paddock 2 had 1 in 1975 and 2 in 1991 and paddock 6 had 21 in 1975

The fire frequency map, (Figure 6) would indicate that paddocks 5, 8 and 3 are burnt the most frequently.

When the DEM is compared to the paddock area if can be seen that the paddocks 5 and 3 have the higher ground and the elevation slowly decreases toward paddock 1.
<table>
<thead>
<tr>
<th>Paddock</th>
<th>DEM: Min</th>
<th>DEM: Max</th>
<th>Fire Frequency 1980 to 2002</th>
<th>Land Units (in order of predominance)</th>
<th>Year Established</th>
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Discussion

The purpose of this study is to identify whether a controlled population of buffalo is affecting the change in woody vegetation in the floodplain of the buffalo farm which was established in 1989.

To determine any change attributable to buffalo in the buffalo farm it is necessary to determine the pattern of change in the study site before the buffalo farm was established and to establish the drivers of this change. The possible drivers include variables such as feral buffalo history, fire regimes, land systems and elevation.

Change before the establishment of the buffalo farm

From 1964 to 1991, the entire study site was open to the same influences. By 1991 feral buffalo had been removed from all areas and the buffalo farm had been established. The 1991 photographic coverage is the closest to the date of establishment of the buffalo farm. While the buffalo farm had certainly been established by 1989 the influence of it’s presence on the floodplain between its establishment and the 1991 photographic coverage would be minimal as the initial stock on the farm were hand fed, numbers were low, with only 339 buffalo and 50 steers on the farm at that time, and the 1991 photographic coverage was taken in the early dry season before significant grazing could occur for the year.

There has been significant increase in woody vegetation over the entire study site in the 40 years from 1964 to 2004 (Figure 22). This increase appears to reflect the density of buffalo population at any point in time and can certainly be linked to the removal of feral buffalo from the area. Marked increase in woody vegetation is coincident with the removal of feral buffalo (Department of Environment and Heritage, 2004a; Friend G.R. and Taylor J.A., 1984; Petty A. et al., 2005; Robinson C.J. and Whitehead P., 2004; Skeat A.J. et al., 1996).
Figure 22: Classified study site. 1964

Figure 23: Classified study site. 2004
When change in woody vegetation is looked at over the whole study site it is found that on average there was no change from 1964 to 1975. The trend of increasing woody vegetation from that point echoes the removal of feral buffalo from the area. The small increase in woody vegetation from 1975 to 1984 reflects the reduction to buffalo numbers and the larger increase from there on reflects their entire removal from the study area. The average rate of increase in woody vegetation over the entire study site from 1964 to 1984 was a minimal 0.37% per annum. From 1984 to 1991 this rate of change increased to 0.67% per annum. From 1991 to 2004 this overall rate of increase in woody vegetation rose to an average of 3.77% per annum. This is a marked increase able to be directly linked to the almost complete removal of feral buffalo between these dates (Bayliss P. and Yeomans K M., 1989a; Department of Environment and Heritage, 2004a; Skeat A.J. et al., 1996).

It cannot however be assumed that all change is attributable to buffalo and various other drivers of change must be considered. The most significant other across the board factor is the rise in greenhouse gasses, in particular CO₂, with the increase in woody vegetation that this is know to bring (Berry S.L. and Roderick M.L., 2002). CO₂ has risen 20% over the last 200 years and whilst it may certainly be an influence in the increase in woody vegetation I believe it would not be expected to bring a change of the magnitude seen in this study site. The increase in woody vegetation has not been equal across the study site with some subsets changing at quite markedly different rates from each other which would indicate other variants. If CO₂ were a major driver of change the woody vegetation increase would be more consistent.

Different fire regimes can have either positive or negative influence on the growth rate of woody plants dependant on the type of and the frequency of fire. A fire set back to vegetation would be more likely to have occurred in the years that showed the greatest increase in woody vegetation after buffalo were removed when fuel loading would have increased. While it is not possible in this study to ascertain the type of fire that has influenced the
study site it is known from fire frequency data that some paddocks have had more frequent burning than others and some areas are burned infrequently.

Elevation may also contribute to variation in vegetative response over time. Elevated areas experience less time inundated which may contribute to an increase in woody vegetation. Surrounding elevated landforms may provide varying catchment capacity for any precipitation that occurs in the drier parts of the year and so may serve to increase growth of woody vegetation at this drier time.

There are various land units throughout the study site and they may be responsible for different rates of growth of woody vegetation as each land unit is suited to differing vegetative species. However, the influence that the varying land units have on vegetation should be constant over time and so should affect trends consistently.

These various drivers of change are, apart from the presence of buffalo and the unpredictability of fire, consistent over time and will have contributed to change from 1964 to 2004 consistently. The pattern of change for the entire study site should be consistent from 1964 to 1991 and onward to 2004. This has not happened.

The main variable to affect the study site from 1964 to 1984 was the presence of and the removal of feral buffalo. It is known that the highest density of feral buffalo was around the mid 1970’s (Letts G.A., 1979; Lindner D., 2005; Petty A. et al., 2005; Skeat A.J. et al., 1996; Werner P A. et al., 2005). From 1964 to 1991 the two subsets outside the buffalo farm, the west floodplain and the buffalo farm fringe, increased woody vegetation by approximately the same amount however the west floodplain area had previously decreased woody vegetation by almost 20% from 1964 to 1975 and did not begin more than a marginal increase until after 1984. The west floodplain increased woody vegetation from 1984 to 1991 immediately after
the removal of feral buffalo by an average of 4.26%pa. This increase is greater than any other subset to 1991 and would indicate a dramatic regeneration after the removal of feral buffalo (Figure 24).

West floodplain 1975 - 2004

![Figure 24: West floodplain 1975 and 2004](image)

Inside the farm did not suffer any loss in vegetation at any time from 1964 to 2004 unlike the outside farm area, in particular the west floodplain.

The area from which the paddocks were later created recorded quite varied rates of woody vegetation increase between 1964 and the creation of the buffalo farm. It needs to be established what the drivers were for this varied change that took place before the buffalo farm was established so that allowance is made for them in the analysis of change once the paddocks are grazed by buffalo. The change in woody vegetation varies from paddock 8 (Figure 21) which recorded a 3% or 0.1%pa increase from 1964 to 1991 to paddock 5 which recorded a 64% or 2.37%pa increase to 1991. From 1984 to 1991 the subset from which paddocks were formed pre 1992, paddocks 1 to 5, began to develop differently, increasing woody vegetation at a slightly greater rate than the area that paddocks were formed from post 1992 (Figure 21). It is interesting that this disparity of change began from 1984 not from 1991 the closest coverage to the creation of the buffalo farm and would indicate change that is not buffalo farm related. It is possible but unlikely that these areas had different densities of feral buffalo. It is also possible that the subset of the buffalo farm that the initial paddocks were created from was better land and able to support a greater increase in vegetation after the
area for any run off from the surrounding land. It may be that these area receive more water run off in the late dry season which extends the growing season for woody vegetation situated in that area. There certainly appears to be a correlation between higher elevation and greater increase in woody vegetation.

The land units that the floodplain paddocks are on are a combination of Cyperus, Copeman and Kosher and Jay land systems. There is a mixture of Cyperus and Copeman throughout the subset of the study site outside the buffalo farm and all 4 land systems are present in the 8 paddock areas. Paddock 5 is the only paddock to be almost entirely on the Jay system. The west floodplain has a small area of Knifehandle.

Fire patterns could also be a factor in variation of change but it is more likely that the areas that had the greatest vegetation increase would have been burned more as these were the areas with the higher elevation and so dried out sooner. The smaller internal paddocks are also the components of the floodplain that have a greater proportion of woody vegetation to plain in area and consequently have more vegetation to burn. The fuel loading in the floodplain generally before the removal of buffalo was generally low because of the heavy grazing and so it is unlikely that fire would have a major effect in the years before the buffalo were removed.

It would seem that the greater increase in woody vegetation in certain areas is linked to the elevation of the land. It may be that there are other variables that have not been able to be identified from the aerial photographs and subsidiary information available to me.

It is of interest to note that channel numbers peaked in 1975 at the time of highest density of buffalo. It is also of interest that channel numbers inside the farm were less than those outside the farm and that several paddock areas recorded no channel sample points at all. While the number of channel points is minimal, and is not to be relied upon, the trend of channel points does echo the channel change study findings (Petty A. et al., 2005).
The low number of channel points within the buffalo farm area, together with
the increase in woody vegetation in that area between 1964 and 1975 would
indicate that this area did not have the density of feral buffalo that the outside
areas, in particular the west floodplain had.

**Change after establishment of the buffalo farm**

Based on demonstrated performance from 1984 to 1991, after the removal of
feral buffalo and with no changes to variables, it could be expected that the
buffalo farm area would increase at a consistent 1% per annum and the
outside subset at 2% per annum. This has not been the case. From 1991 to
2004 the subset outside the buffalo farm has increased its annual percentage
increase in woody vegetation to 3.75% per annum a rate almost double the
1984 to 1991 rate of increase. The subset of inside the farm has increased
by an average of only 0.98% per annum, the same rate or very slightly less
than the average increase from 1984 to 1991. The one variable is presence
of the buffalo farm.

The buffalo farm fringe has had quite different results from the other areas. It
increased woody vegetation quite moderately to 1991 and then has
increased at a considerably higher rate from then. The minimal change from
1984 to 1991 can not be explained in this report. All areas of tier three, the
buffalo farm fringe, west floodplain, the area that paddocks were created
from prior to 1992 and the area that paddocks were created from post 1992,
have shown increase in woody vegetation form 1991 and 3 of the 4 subsets
including the buffalo farm paddock areas have increased at the same rate
from 1991 to 2004. This is indicative that there is no dramatic detrimental
effect from the buffalo on the buffalo farm. The much greater rates of
increase in woody vegetation outside the buffalo farm from 1991 to 2004
would however indicate that the presence of buffalo in the farm is inhibiting
the increase in woody vegetation. In Table 3: percentage gain 1984 to 1991
and 1991 to 2004, Figure 20: Tier 3 graph, it can be seen that the two
paddock subsets follow a different trend to the outside areas from 1991.
When the two paddock area are compared to each other it can be seen that the subset from which paddocks were formed after 1992 has increased in woody vegetation at a much smaller rate than the pre 1992 paddock area. If buffalo grazing was having a marked effect on the paddocks it would be a probability that the paddocks formed before 1992 would show the most impact with the least increase in woody vegetation. This is not the case. The post 1992 paddock area has the lowest rate of increase.

Table 3: percentage gain 1984 to 1991 and 1991 to 2004

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<tr>
<td>Post 1992 paddock area</td>
<td>0.68</td>
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</table>

The paddock areas are in fact an amalgamation of paddocks and each paddock has had different management and use since 1989. Different variables such as management use, fire regime, land units elevation and position within the floodplain affect each paddock uniquely. It is then important to isolate each paddock and evaluate its change in comparison to the other paddocks to ascertain if any particular variable can be identified as an inhibitor to woody vegetation increase.

The only variables identified, that affect all paddocks after 1991 and may be different from the variables before the establishment of the farm, are fire regime and buffalo numbers. The buffalo farm manager has been shown the fire frequency data and asserts that it is inaccurate and that many areas of the buffalo farm are in fact burned far more frequently than the data would suggest. The fire data records whether an area has been burned or not in an individual year. Some areas burn more frequently than once a year and this is not reflected in the data (Lindner D., 2005). If the buffalo farm paddocks
are burned more frequently it is possible that the woody vegetation in these paddocks either benefits from the fires due to low fuel loading in the basal area from constant burning or alternatively it is retarded in its growth by the continual loss of foliage and the nutrient expenditure required to replace foliage (Werner P A. et al., 2005) It is not possible in this report to ascertain the answer to this. The farm manager burns consistently throughout the dry season so that fresh feed is available and it can be assumed that all paddocks are burned.

The other management factors affecting the paddocks are the date of establishment of the paddock and whether the paddock is used in the early or late dry season. The paddocks formed after 1992 are all used in the late dry season with one exception and the paddocks formed before 1992 are used in the early dry season.

**Paddocks formed after 1992**

Paddock 6 is a special case as it was formed in 1997 into two component parts and while it has been used for grazing in the early dry season it is now regarded by the farm manager as derelict and unusable. This paddock is the only floodplain paddock situated at the northern end of the buffalo farm and is also the only paddock situated on the Copeman land system. The Copeman land system has a tendency, more than the other land systems, to be swampy. It is also possible that the more northern aspect of this paddock may allow some influence from salt water. The figures for this paddock would indicate that it increased in woody vegetation from 1964 to 1991 at an average rate of 0.64%pa and maintained this rate from 1991 to 2004, a low but constant increase. Paddock 6 should not be considered as indicative of the influence of buffalo as it has only been used for a short period of time within the 1991 to 2004 time frame and is now disused.
The other two early dry season paddocks are numbers 7 and 8. They are situated on opposite sides of the main floodplain and where paddock 7 is a bay like area paddock 8 encompasses a long finger of floodplain. Paddock 7 has more low plain areas than paddock 8. According to fire frequency data paddock 8 has considerably more frequent fire than paddock 7 (Figure 6: Fire frequency). These two early dry season paddocks have increased in woody vegetation since 1991 quite differently. There is no consistency between them. Paddock 8 increased in woody vegetation the least of any subset of the study site from 1964 to 1991. While the rate of increase has lifted very slightly it still has the lowest increase of any subset and has recorded only a 5% increase in woody vegetation since 1964 where paddock 7 recorded a 26% increase. When the 1964 and 2004 aerial photographs of paddock 8 are inspected, (Figure 25, Figure 26) it can be seen that this area has always maintained a consistent coverage of woody vegetation on the fringe and has little vegetation in the plain area. Although paddocks 7 and 8 have a similar history they have changed quite differently from each other. It may be that the fire regimes in each paddock or the geomorphic or topographic differences are sufficient to enable this difference. Paddock 8 does have a greater area of lower plain than paddock 7. It also may be that the presence of buffalo has had more effect on one paddock than the other. There is also the possibility that paddock 8 is near maximum woody vegetation capacity and consequently is not capable of greater increase.

**Paddocks formed before 1992**

Paddocks 1 to 5 are divisions of the main buffalo farm floodplain and have increased in woody vegetation in similar fashion to each other from 1964 to 1991. In comparison to each other the rate of increase of woody vegetation in each paddock from 1991 to 2004 follows the pattern pre 1991 with paddock 5 the most internal paddock increasing at the greatest rate descending down through the other paddocks to paddock 1 with the least increase. This increase is positively related to the elevation of each paddock with the paddocks with the higher land recording a greater increase in woody vegetation. (Figure 7)
Paddock 5 has achieved far greater growth in woody vegetation than any other subset. As mentioned in results, between 1991 and 2004 this paddock increased woody vegetation at a rate three times greater than the next nearest increase which was in paddock 4 adjacent to it. This increase is quite out of proportion to any other increase in any other subset of the entire study site. Paddock 5 has differences to the other paddocks. It has the highest elevation, it is situated entirely on Jay land unit and it is the tail end of the floodplain and has with a billabong area within it. It could be argued that this area is not true floodplain. The combination of these factors would suggest that this paddock is inundated for less time, it would be the first area to receive run off from any dry season or early precipitation. It also has permanent water by way of the billabong on it. It is also the smallest of paddocks and has only 85 sample points within it which may lead to bias in the percentage change. This paddock is also the home paddock and it has not been possible to establish whether it is used for grazing. It is known that this paddock is burned frequently for the protection of the home. It is not possible here to establish the reason for the difference in woody vegetation increase in this paddock.
Conclusion

The buffalo farm area would appear to have not been as badly affected by feral buffalo as the west floodplain area.

The paddock areas have increased woody vegetation at a substantially lower rate than the subsets of west floodplain and the buffalo farm fringe. Each subset of the study site is situated on varying combinations of land units, has differing fire regimes, elevation and has had varying densities of feral buffalo. It could be expected that with the removal of the uncontrolled buffalo population some years ago the current increase in woody vegetation would be similar between subsets. This is not the case.

Paddocks 7 and 8 the two early dry season paddocks have increased in woody vegetation at very low rates. It may well be that this is an influence from the grazing of buffalo. There is however some increase in woody vegetation which would indicate that the influence of the controlled population is not as detrimental as the feral buffalo numbers prior to the establishment of the farm as these two paddocks recorded virtually no increase in woody vegetation from 1984 to 1991.

Paddocks 1 to 5 have recorded various rates of increase but with the exception of paddock 5 which has recorded quite different results to any other subset no other paddock has equalled or exceeded the rate of woody vegetation increase of the subsets outside the farm. It certainly may be that there was not the room for increase because this area was not as badly affected by feral animals before BTEC but the fringe area of the farm would have been influenced by the same density of animal and it has increased in woody vegetation at a far greater rate than any area within the farm.

The pattern of increase of woody vegetation within paddocks 1 to 5 is in direct relation to the elevation of the paddocks with the lowest paddocks recording the least increase. There are of course low areas in the floodplain outside the buffalo farm and these areas have increased woody vegetation at
a greater rate than the low areas in the buffalo farm. It would seem that the effects of grazing limit the expansion of woody vegetation more in the lower land.

This study is preliminary in nature and not conclusive. It would however appear that there is sufficient evidence that buffalo have had some effect on the regeneration of the floodplain. This effect is limited to a retardation of the regeneration and is not degrading the floodplain. It would then appear that with effective management it is possible to graze buffalo on floodplain areas without incurring degradation to the land.

**Further study**

This study is preliminary by nature and indicates that there has been an effect on woody vegetation from the buffalo on the buffalo farm. To analyse the magnitude of that effect it would be necessary to analyse further than has been possible within this study. Further study would allow more specific detection of the factors that drive the trends of change and to relate them to the varying densities of both feral buffalo and buffalo numbers within the farm.

Further investigation is necessary into paddock 5 to attempt to ascertain what the, as yet unidentified, factors are that have resulted in such a dramatically different response in that area.

The use of satellite imagery with infra red bands would enable NDVI coverage of the buffalo farm floodplain and the floodplain outside the farm. This coverage should be timed so that it was calculated before the use of each paddock area in any year and at the end of use of the paddock areas for the year. It would be possible to then calculate the change in vegetation inside and outside the farm and to ascertain any different trends. It may be possible with satellite imagery to also identify species specific change.

It would appear that one of the major influences on increase in woody vegetation is elevation. Further study is needed to analyse and compare and
contrast the change in woody vegetation in the various elevations across the entire study site.

Specific analysis of change and trends within each of the land units may also provide further information as to its influence on vegetative change.

The use of statistics and modelling as a predictor of change in the future could be employed as a management tool.

Further analysis of the classification should be carried out to determine the common factors in the components of the study site as a whole that have shown the greatest change.

This study focuses on the floodplain area of the buffalo farm. To accurately estimate the impact of buffalo on the farm it is necessary to analyse the savanna and also the riparian areas of the farm.

This study has been one of general change in woody vegetation it has not identified the specific species involved. The identification of the change within specific species of both flora and fauna may be instructive.

Limitations
While there were several limitations for this study the main limitation has been one of time as this is a one semester unit.

The location and collection of photographic data and the preparation of it was a time consuming exercise and limited the time available for the classification and analysis of data.

Time constraints have also dictated that it has not been possible to ascertain in depth statistical analysis of data.

Time was also a problem for ground survey of the buffalo farm as the floodplain areas were inundated and inaccessible for that purpose. As all
photography was taken in May, June or July these would be the preferable months for ground survey to compare like with like.

The photographic coverages were of varying quality and two coverages were black and white. These poorer quality coverages are more difficult to interpret. Classification of the photographic data was limited to the coarse, non species specific, classes of forest and scrub then combined into woody vegetation.

The classification data was limited to aerial photographs only. It would be preferable to have classified an early 1980, 1991 and a 2004 satellite coverage to confirm general trends in woody vegetation change.

Although ever effort was made to rectify all photographs precisely there is always a small degree of error in the rectification process. This error will result in a not quite exact comparison of geographic points in the point grid analysis. The 15 metre sample point will have, by its size of sample, helped reduce any error that may have resulted from any inaccuracy of registration.

Rainfall data collected for the farm (appendix 2) was limited to the wet season and not able to be used as more than general knowledge of rainfall in the area.

Access to information on the buffalo farm was difficult to access at times as the buffalo farm manger is not contactable except by visitation.
References


Department of Environment and Heritage, 2004c. Management of Kakadu National Park. WWW, Canberra


Harvey K.R. and Hill G.J.E., 2001. Vegetation mapping of a tropical freshwater swamp in the Northern Territory, Australia: a comparison of
aerial photography, Landsat TM and SPOT satellite imagery.


## Appendix 1: Aerial Photograph Lists

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**Total**: 4.5 27 136 220.5 391 338.5 301 93.5

**Grand Total**: 1512mm

nb: Dave Lindner in Brisbane 26 Feb to 1 March therefore 2 march = total for that time

Good year for farm
Appendix 3: Classification data

Tier 1

Class numbers and percentages for entire study area.

Raw numbers of classification points

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Percentage of coverage for individual classes

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<tr>
<td>2004</td>
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Percentage of 1964 coverage.

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Tier 2: Percentage of 1964 coverage

Inside buffalo farm

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Outside buffalo farm

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### Tier 3: Percentage of 1964 coverage

#### Buffalo farm fringe

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#### Area that paddocks were formed from before 1992

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#### Area that paddocks were formed from after 1992

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Tier 4: Percentage of 1964 coverage

Individual paddocks

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<td>147.06%</td>
</tr>
<tr>
<td>2004</td>
<td>71.96%</td>
<td>158.82%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Paddock 4</th>
<th>No woody vegetation</th>
<th>Woody Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
<tr>
<td>1975</td>
<td>77.67%</td>
<td>130.67%</td>
</tr>
<tr>
<td>1984</td>
<td>73.79%</td>
<td>136.00%</td>
</tr>
<tr>
<td>1991</td>
<td>73.79%</td>
<td>134.67%</td>
</tr>
<tr>
<td>2004</td>
<td>51.46%</td>
<td>166.67%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Paddock 5</th>
<th>No woody vegetation</th>
<th>Woody Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
<tr>
<td>1975</td>
<td>95.00%</td>
<td>112.00%</td>
</tr>
<tr>
<td>1984</td>
<td>93.33%</td>
<td>116.00%</td>
</tr>
<tr>
<td>1991</td>
<td>73.33%</td>
<td>164.00%</td>
</tr>
<tr>
<td>2004</td>
<td>31.67%</td>
<td>264.00%</td>
</tr>
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</table>
### Paddock 6

<table>
<thead>
<tr>
<th>Year</th>
<th>No woody vegetation</th>
<th>Woody Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
<tr>
<td>1975</td>
<td>98.28%</td>
<td>111.16%</td>
</tr>
<tr>
<td>1984</td>
<td>98.13%</td>
<td>112.09%</td>
</tr>
<tr>
<td>1991</td>
<td>97.34%</td>
<td>117.21%</td>
</tr>
<tr>
<td>2004</td>
<td>95.98%</td>
<td>126.05%</td>
</tr>
</tbody>
</table>

### Paddock 7

<table>
<thead>
<tr>
<th>Year</th>
<th>No woody vegetation</th>
<th>Woody Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
<tr>
<td>1975</td>
<td>88.89%</td>
<td>111.37%</td>
</tr>
<tr>
<td>1984</td>
<td>91.67%</td>
<td>108.53%</td>
</tr>
<tr>
<td>1991</td>
<td>89.35%</td>
<td>110.90%</td>
</tr>
<tr>
<td>2004</td>
<td>74.54%</td>
<td>126.07%</td>
</tr>
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</table>

### Paddock 8

<table>
<thead>
<tr>
<th>Year</th>
<th>No woody vegetation</th>
<th>Woody Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
<tr>
<td>1975</td>
<td>102.70%</td>
<td>98.77%</td>
</tr>
<tr>
<td>1984</td>
<td>97.30%</td>
<td>101.23%</td>
</tr>
<tr>
<td>1991</td>
<td>93.24%</td>
<td>103.07%</td>
</tr>
<tr>
<td>2004</td>
<td>87.84%</td>
<td>105.52%</td>
</tr>
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